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Topliss et al.

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(45) Date of Patent: Oct. 17, 2017

(54) **MINIATURE CAMERA ZOOM ACTUATOR WITH MAGNET-INDUCED FRICTION**

(71) Applicant: **Apple Inc.**, Cupertino, CA (US)

(72) Inventors: **Richard J. Topliss**, Campbell, CA (US); **Richard H. Tsai**, Cupertino, CA (US); **Albert A. Ho**, Mountain View, CA (US); **Thomas M. Gregory**, Cupertino, CA (US)

(73) Assignee: **Apple Inc.**, Cupertino, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 8 days.

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(22) Filed: **Aug. 6, 2015**

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(51) **Int. Cl.**

G02B 13/00	(2006.01)
H04N 5/232	(2006.01)
H04N 5/225	(2006.01)
G02B 7/02	(2006.01)

(52) **U.S. Cl.**

CPC ***G02B 13/009*** (2013.01); ***G02B 7/023*** (2013.01); ***H04N 5/2254*** (2013.01); ***H04N 5/23296*** (2013.01); *G02B 13/001* (2013.01); *G03B 2205/0061* (2013.01); *H04N 5/2257* (2013.01)

(58) **Field of Classification Search**

CPC G02B 13/009; G02B 7/04; G02B 7/08; G02B 7/023; G02B 13/001; G02B 7/102; G02B 7/09–7/10; H04N 5/2254; H04N 5/2253; H04N 5/2257; H04N 5/2252; H04N 5/23287; H04N 5/23296; G03B 3/10; G03B 2205/0046; G03B 2205/0061; G03B 2205/0069; G03B 2205/0053

See application file for complete search history.

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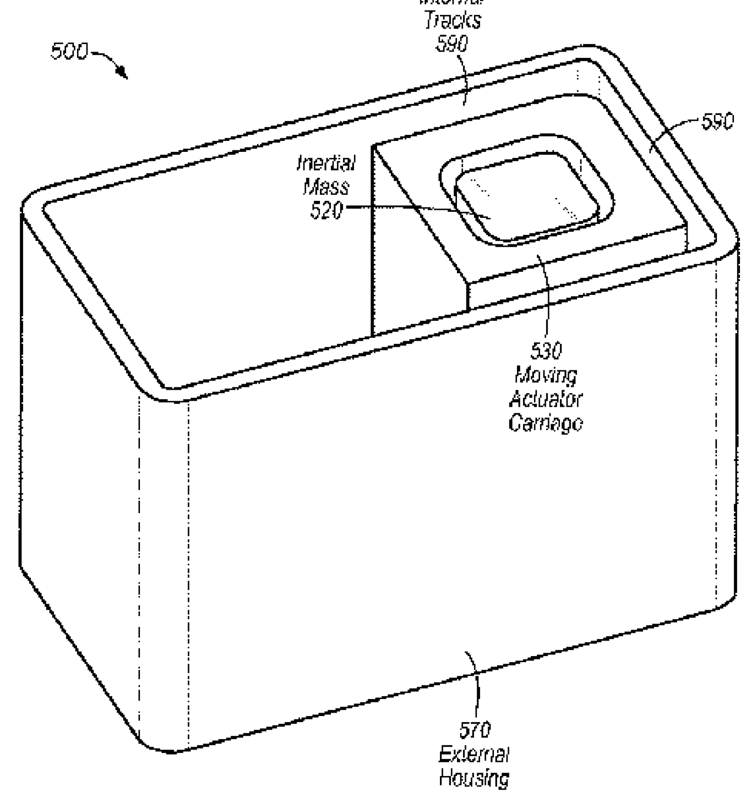
Primary Examiner — Michael Osinski

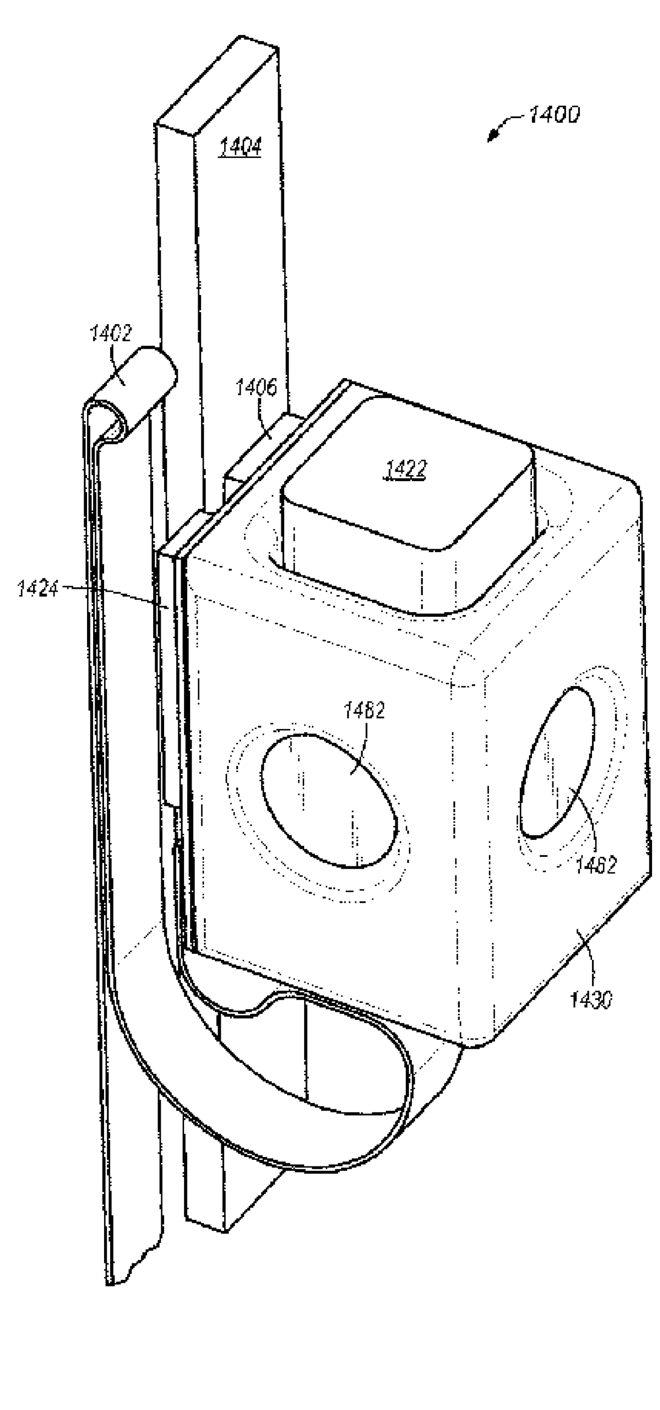
(74) *Attorney, Agent, or Firm* — Robert C. Kowert; Meyertons, Hood, Kivlin, Kowert & Goetzel, P.C.

(57) ABSTRACT

Some embodiments include a fixed chassis structure and a moveable carriage body carrying one or more lenses. The fixed chassis structure includes a magnetic friction track. The moveable carriage body carries one or more lenses. An electrically-controllable magnet is mounted to the moveable carriage body for generating a magnetic attraction force between the magnet and the magnetic friction track. The moveable carriage body is movably mounted to the chassis to allow movement along an optical axis through the one or more lenses. An inertial actuator is mounted to the moveable carriage body in an alignment such that the axis of motion of the actuator is parallel to the optical axis through the one or more lenses. The moveable carriage body is held in place with respect to the at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force.

20 Claims, 18 Drawing Sheets





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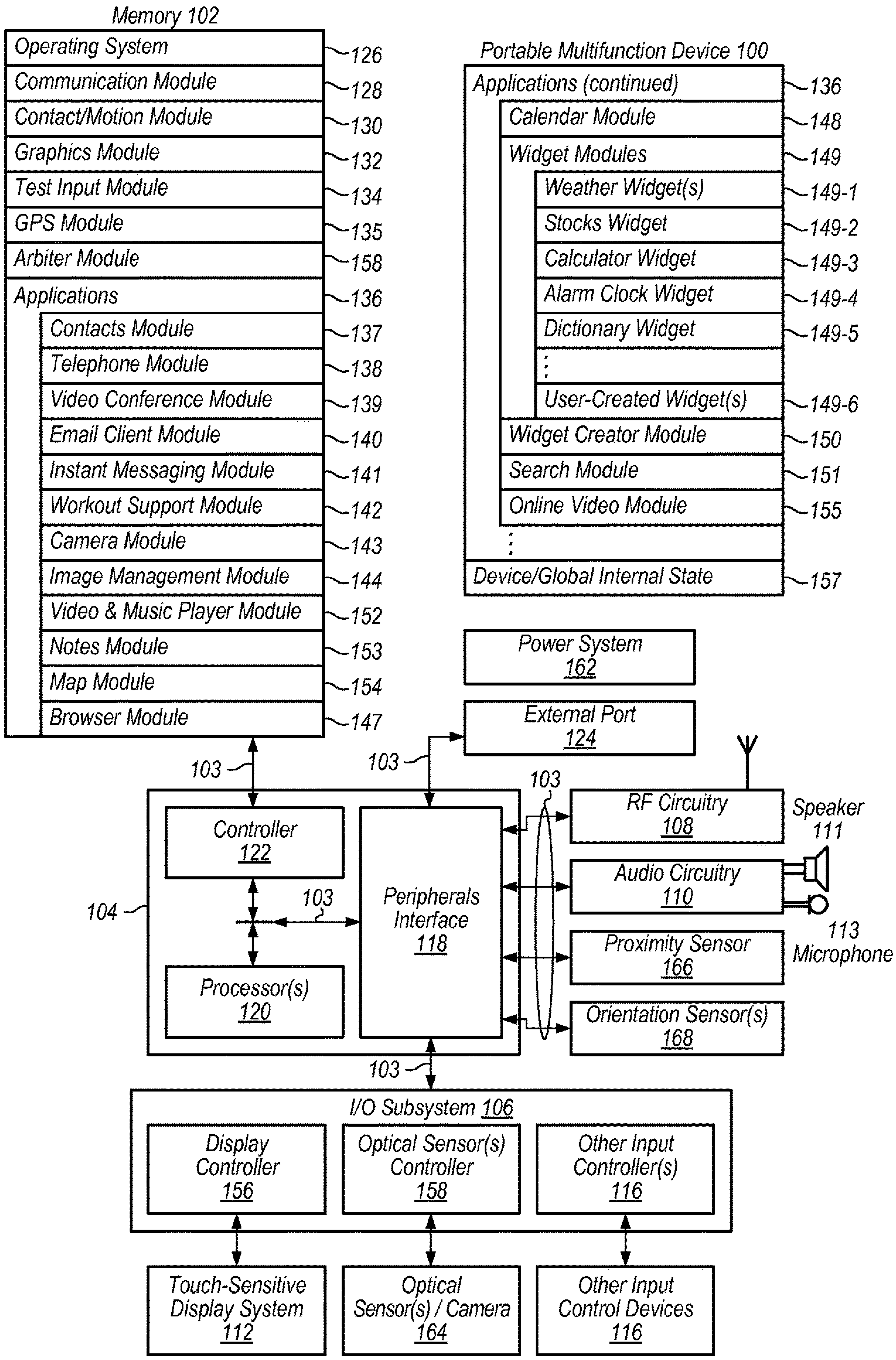

Memory 102
Operating System 126
Communication Module 128
Contact/Motion Module 130
Graphics Module 132
Test Input Module 134
GPS Module 135
Arbiter Module 158
Applications 136
Contacts Module 137
Telephone Module 138
Video Conference Module 139
Email Client Module 140
Instant Messaging Module 141
Workout Support Module 142
Camera Module 143
Image Management Module 144
Video & Music Player Module 152
Notes Module 153
Map Module 154
Browser Module 147
Portable Multifunction Device 100
Applications (continued) 136
Calendar Module 148
Widget Modules 149
Weather Widget(s) 149-1
Stocks Widget 149-2
Calculator Widget 149-3
Alarm Clock Widget 149-4
Dictionary Widget 149-5
User-Created Widget(s) 149-6
Widget Creator Module 150
Search Module 151
Online Video Module 155
Device/Global Internal State 157
Power System 162
External Port 124
103
RF Circuitry 108
Speaker 111
Audio Circuitry 110
Proximity Sensor 166
113 Microphone
Orientation Sensor(s) 168
104
Controller 122
Peripherals Interface 118
Processor(s) 120
I/O Subsystem 106
Display Controller 156
Optical Sensor(s) Controller 158
Other Input Controller(s) 116
Touch-Sensitive Display System 112
Optical Sensor(s) / Camera 164
Other Input Control Devices 116

FIG. 1

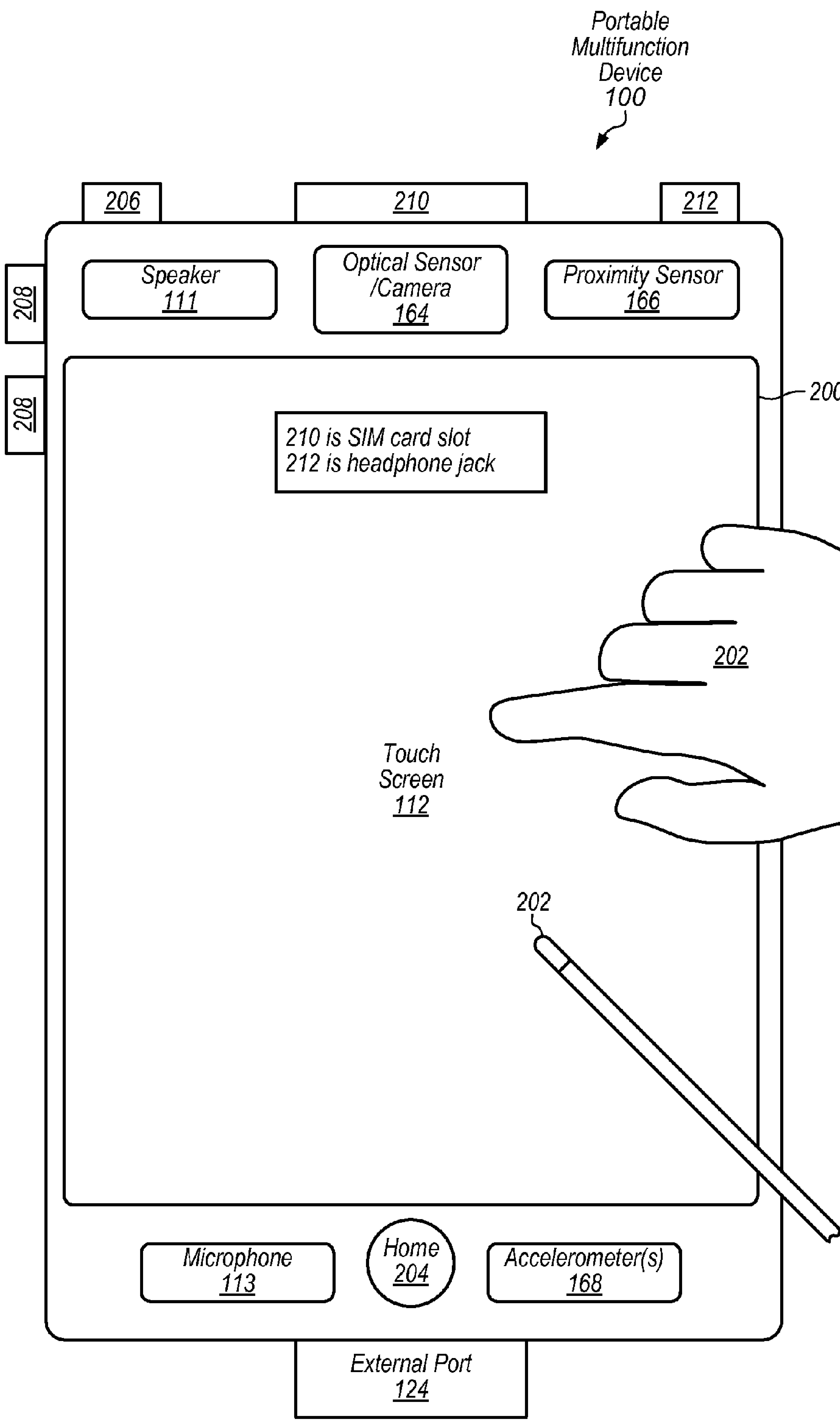

Portable
Multifunction
Device
100
206
210
212
208
208
Speaker
111
Optical Sensor
/Camera
164
Proximity Sensor
166
200
210 is SIM card slot
212 is headphone jack
202
Touch
Screen
112
202
Microphone
113
Home
204
Accelerometer(s)
168
External Port
124

FIG. 2

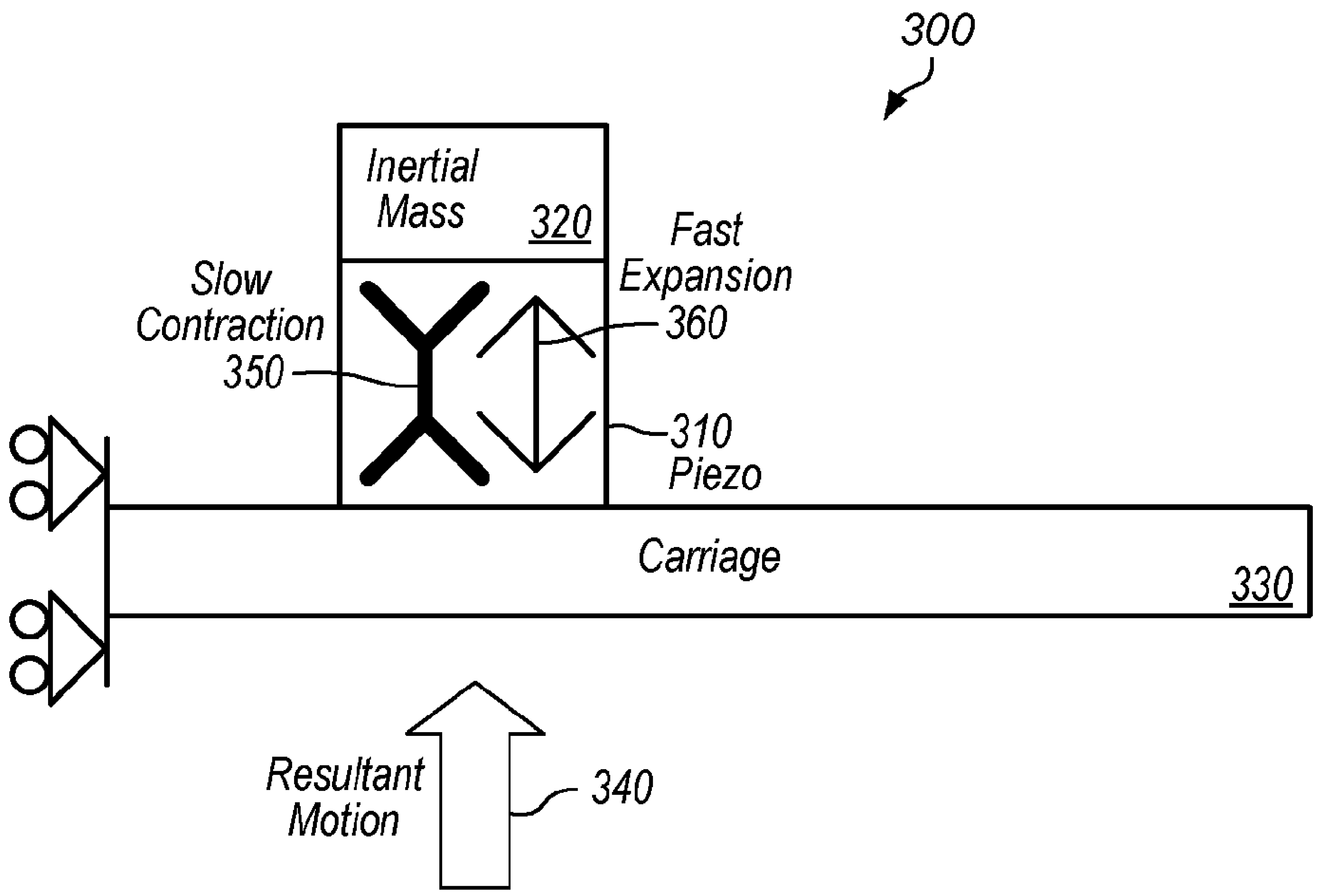

300
Inertial Mass 320
Slow Contraction 350
Fast Expansion 360
310 Piezo
Carriage 330
Resultant Motion
340

FIG. 3

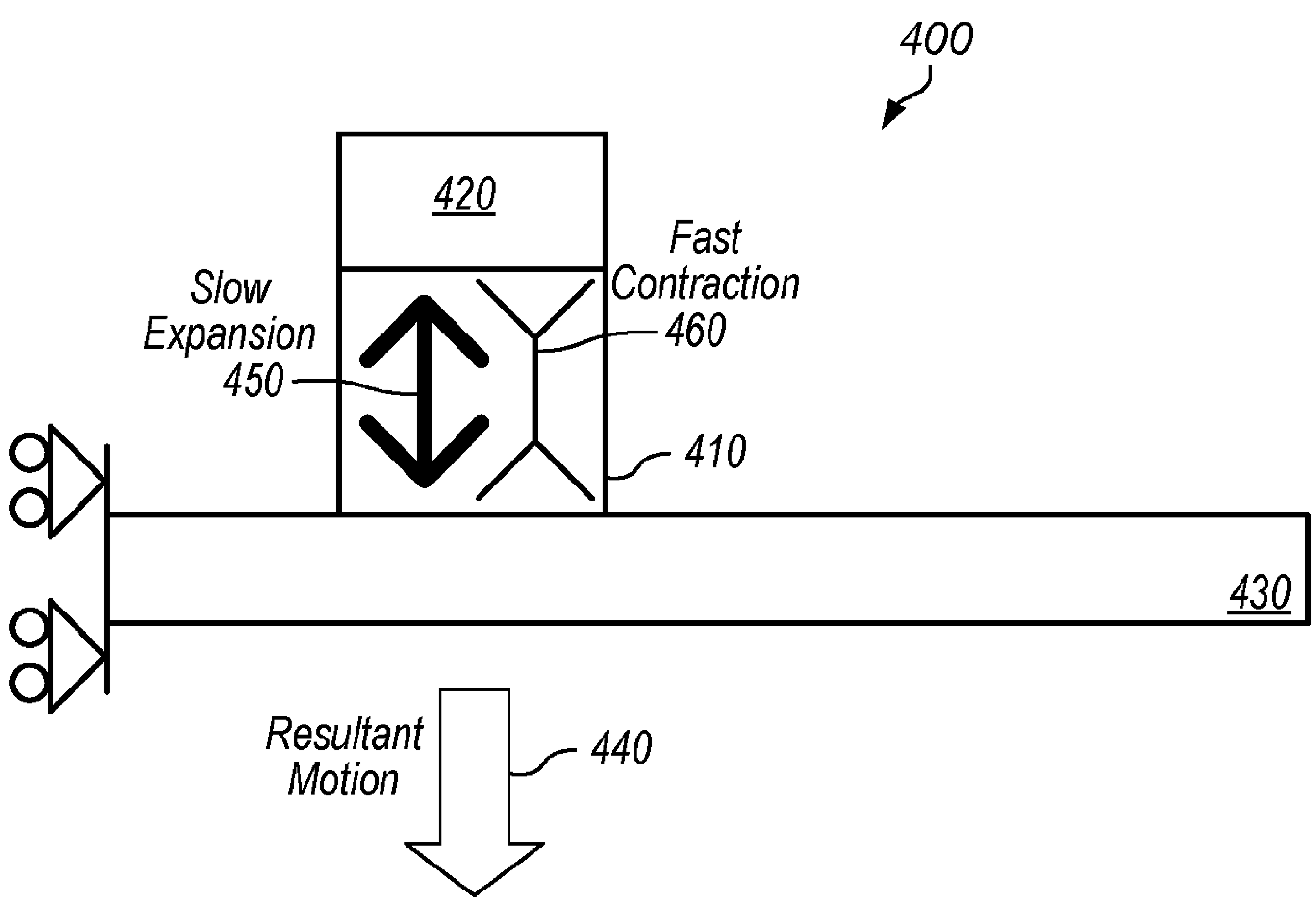
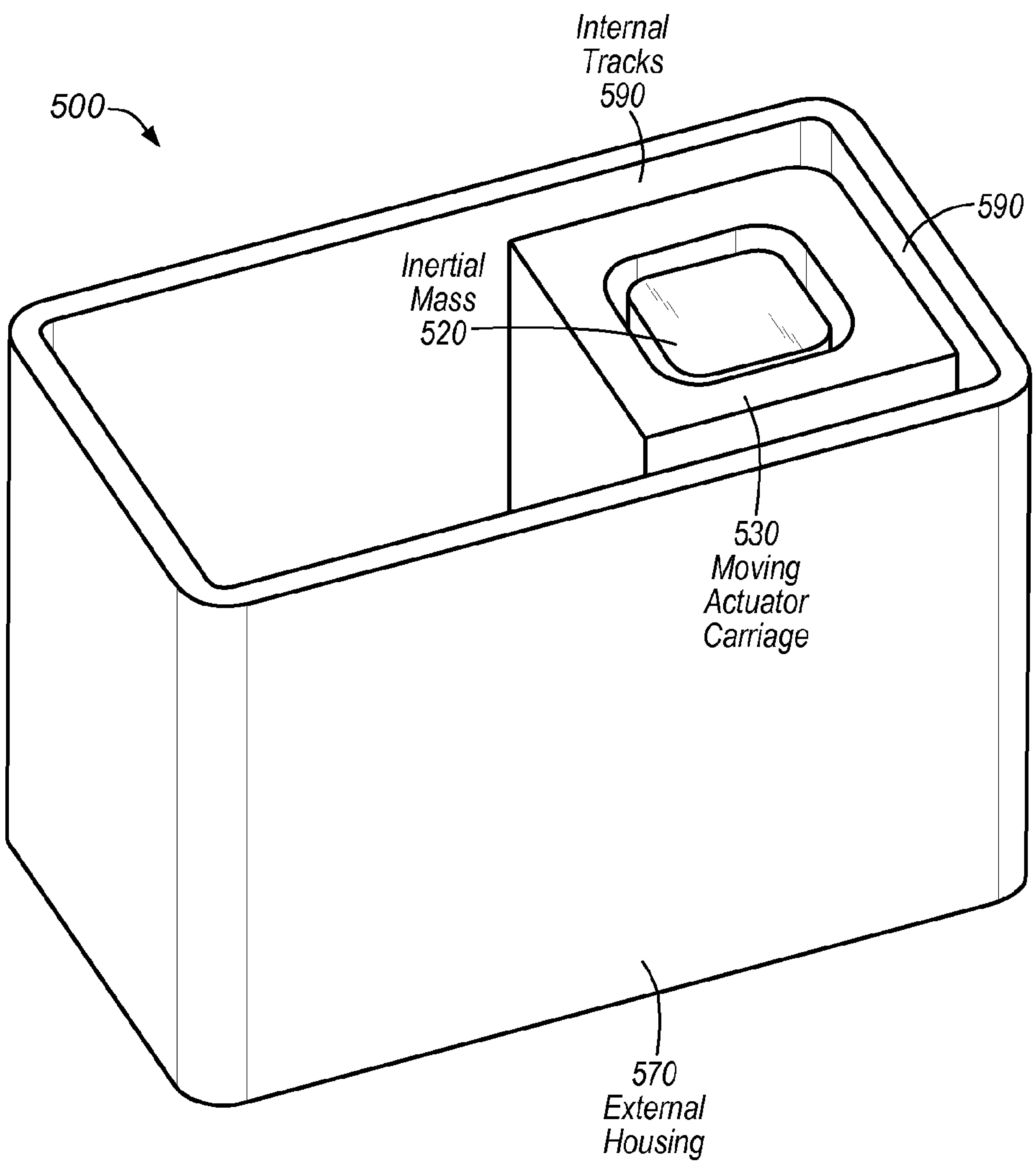

400
420
Slow Expansion 450
Fast Contraction 460
410
430
Resultant Motion
440

FIG. 4



500
Internal Tracks 590
590
Inertial Mass 520
530 Moving Actuator Carriage
570 External Housing

FIG. 5

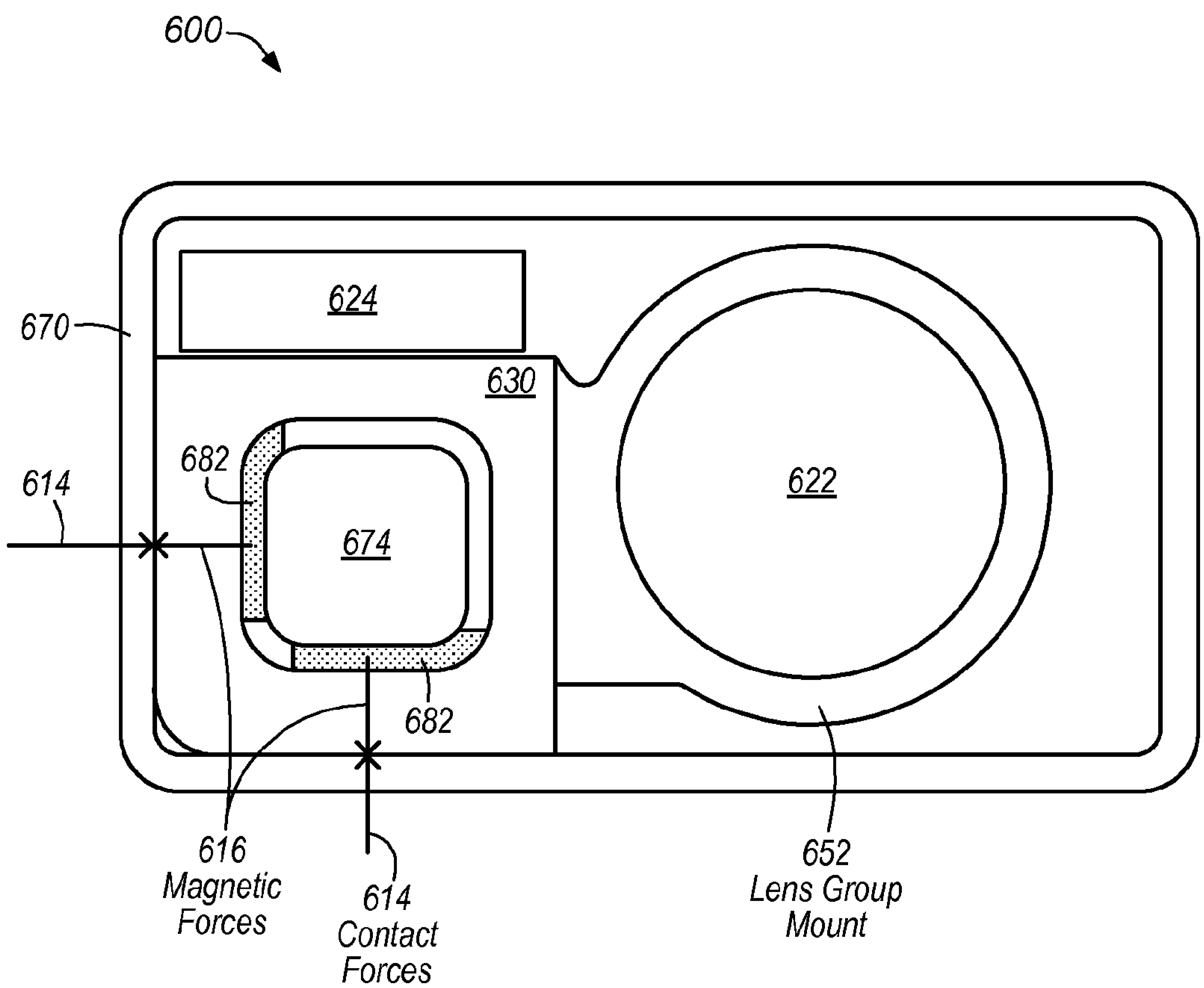

600
670
624
630
682
614
674
622
682
616
Magnetic
Forces
614
Contact
Forces
652
Lens Group
Mount

FIG. 6

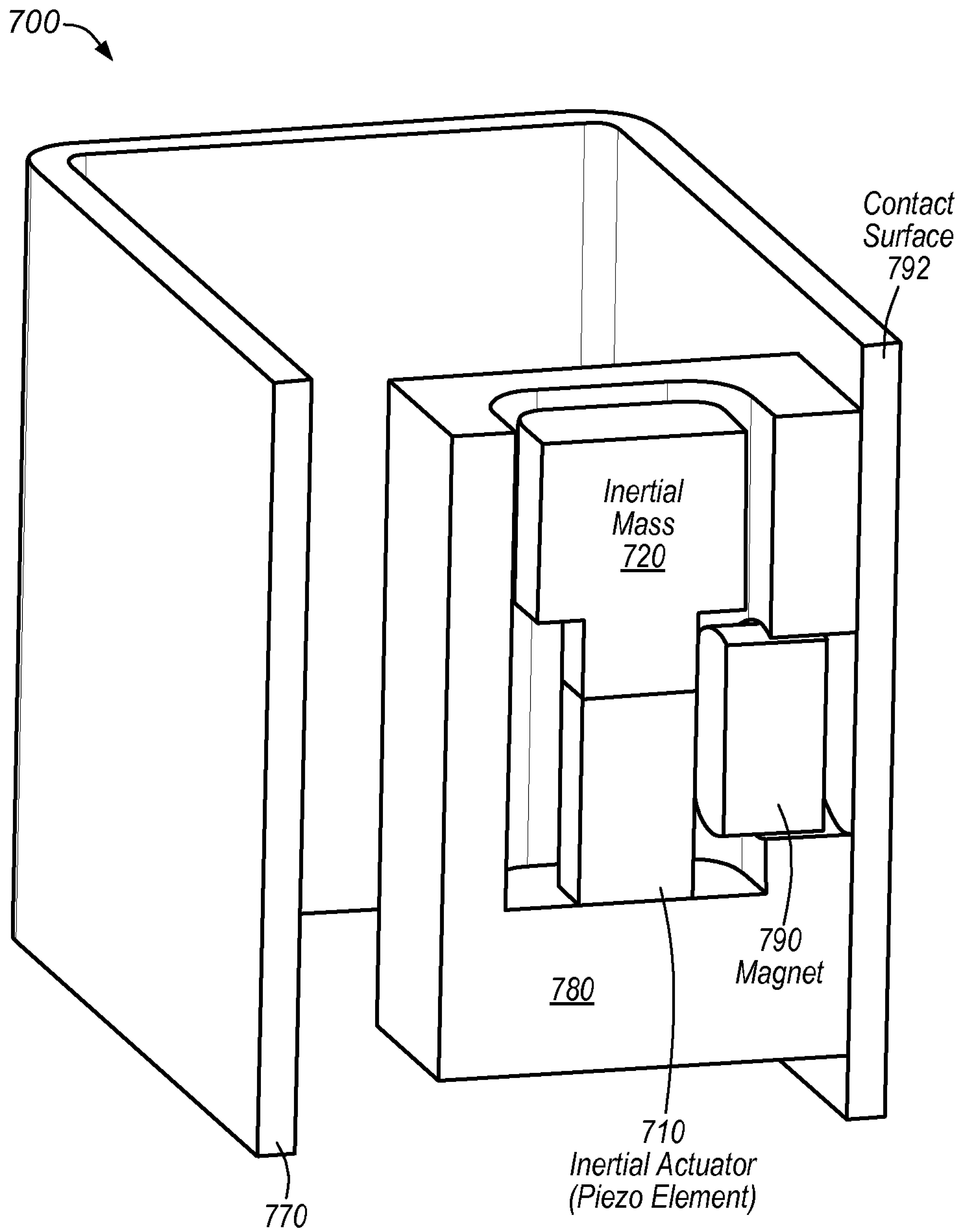

700
Contact Surface 792
Inertial Mass 720
790 Magnet
780
770
710 Inertial Actuator (Piezo Element)

FIG. 7

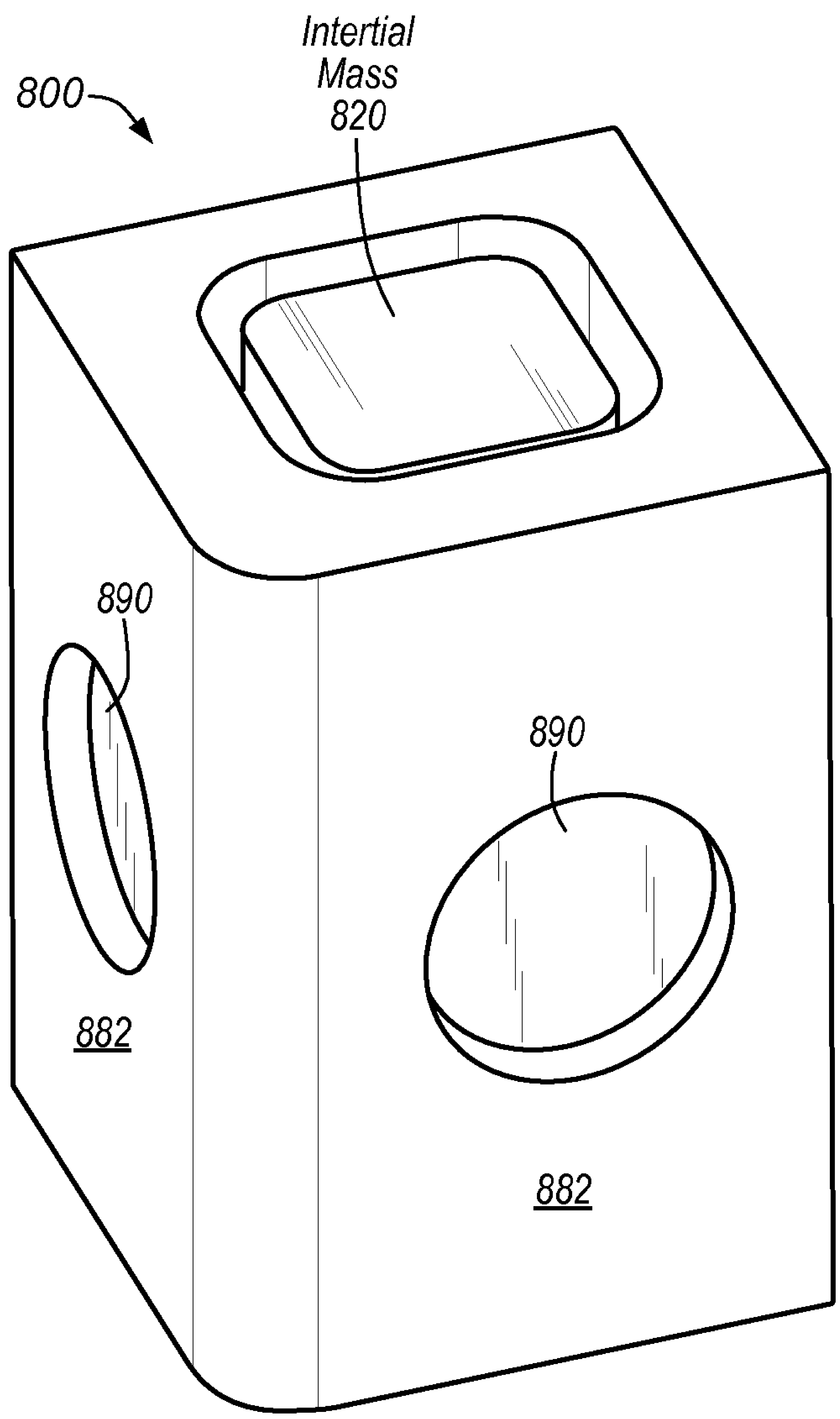


FIG. 8

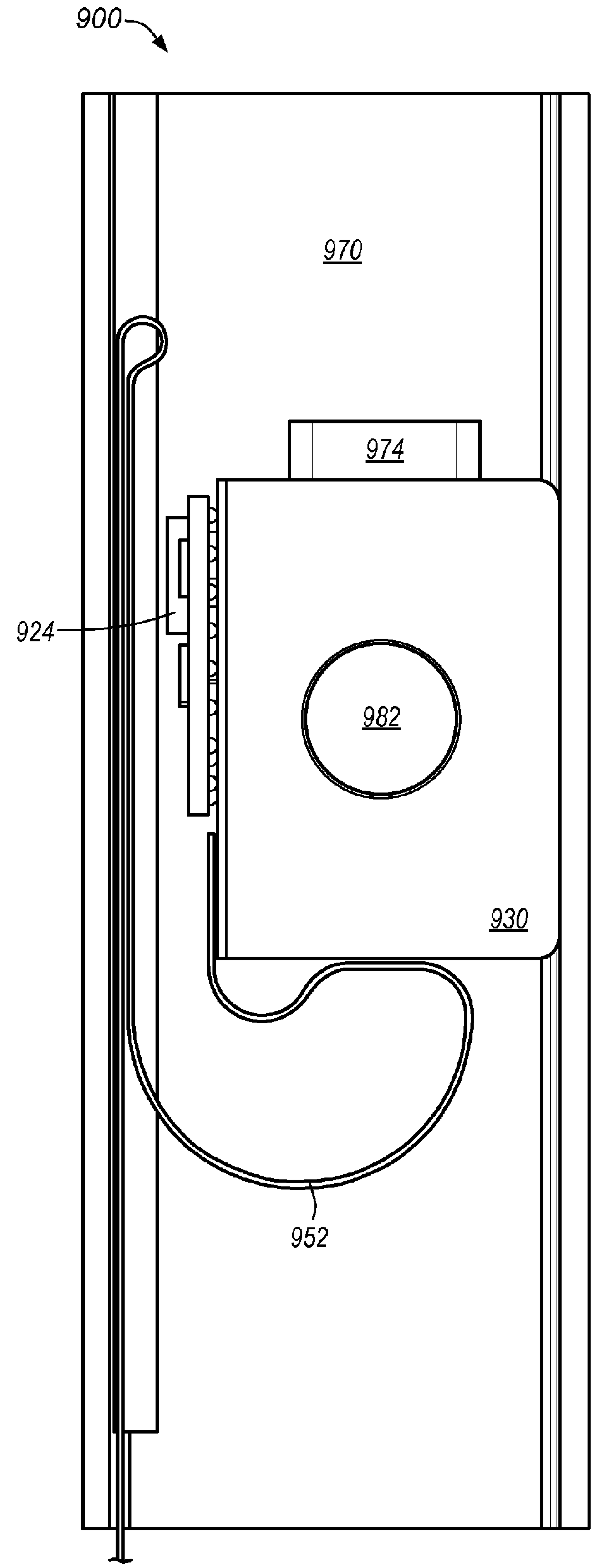


FIG. 9

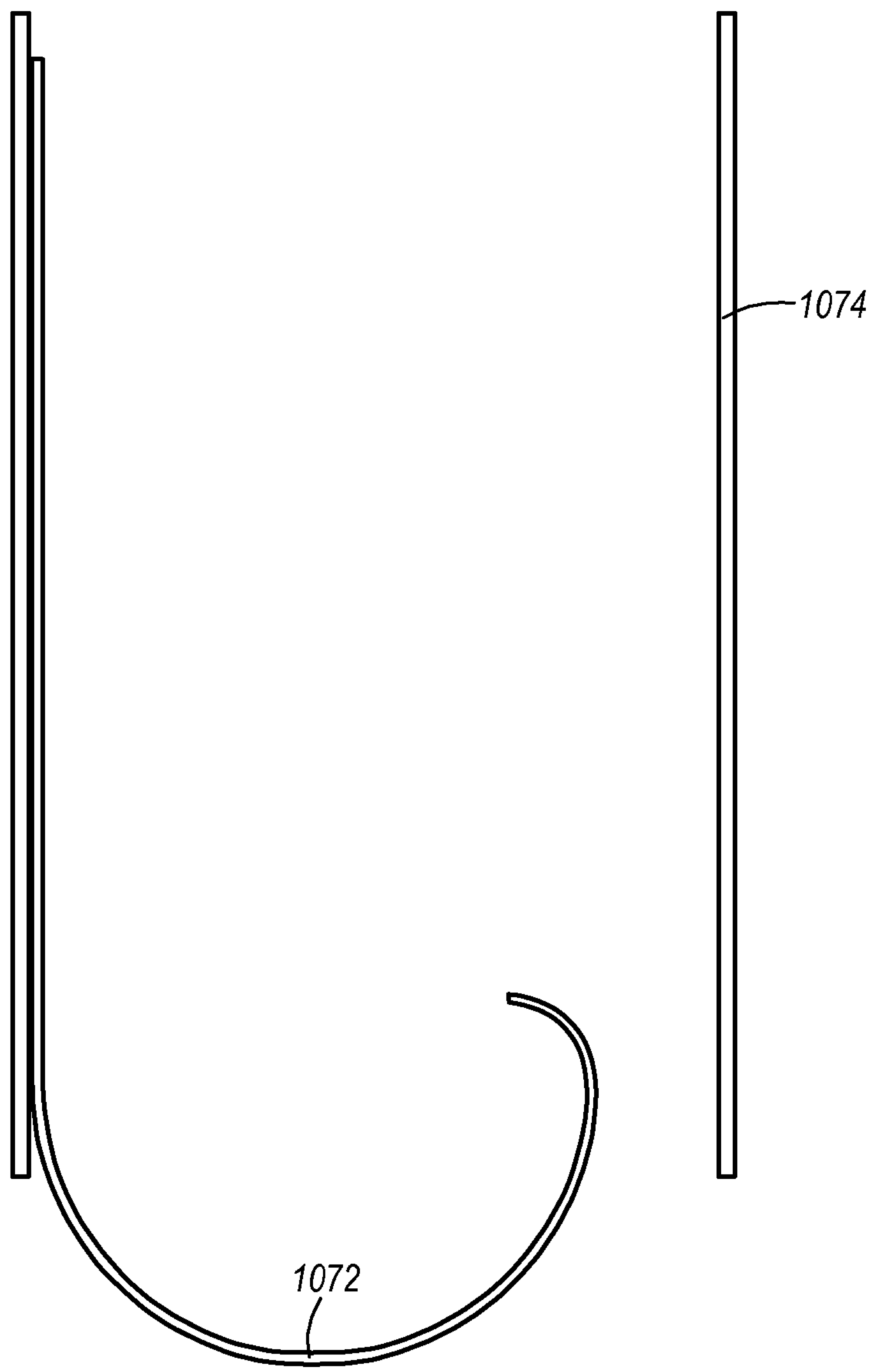


FIG. 10

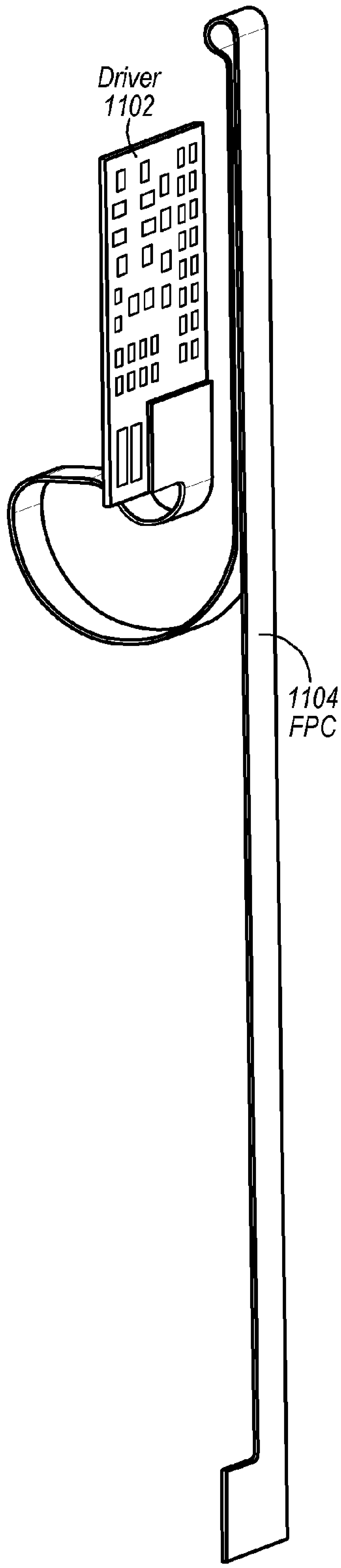


FIG. 11

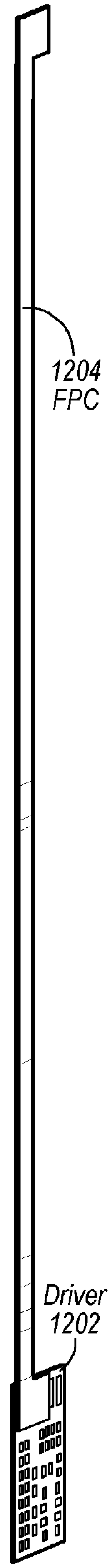


FIG. 12

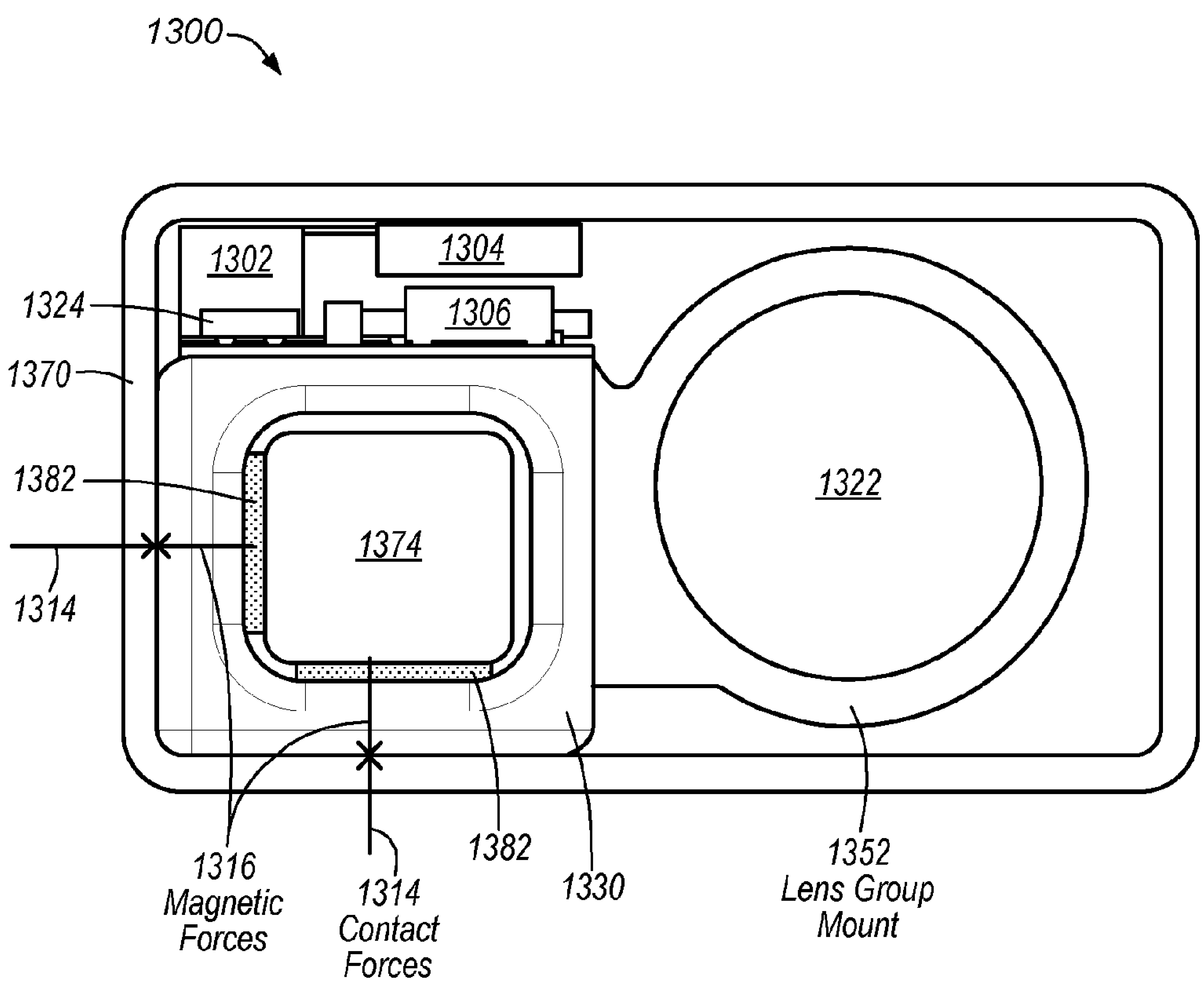

1300
1302
1304
1306
1324
1370
1382
1374
1322
1314
1316
Magnetic
Forces
1314
Contact
Forces
1382
1330
1352
Lens Group
Mount

FIG. 13

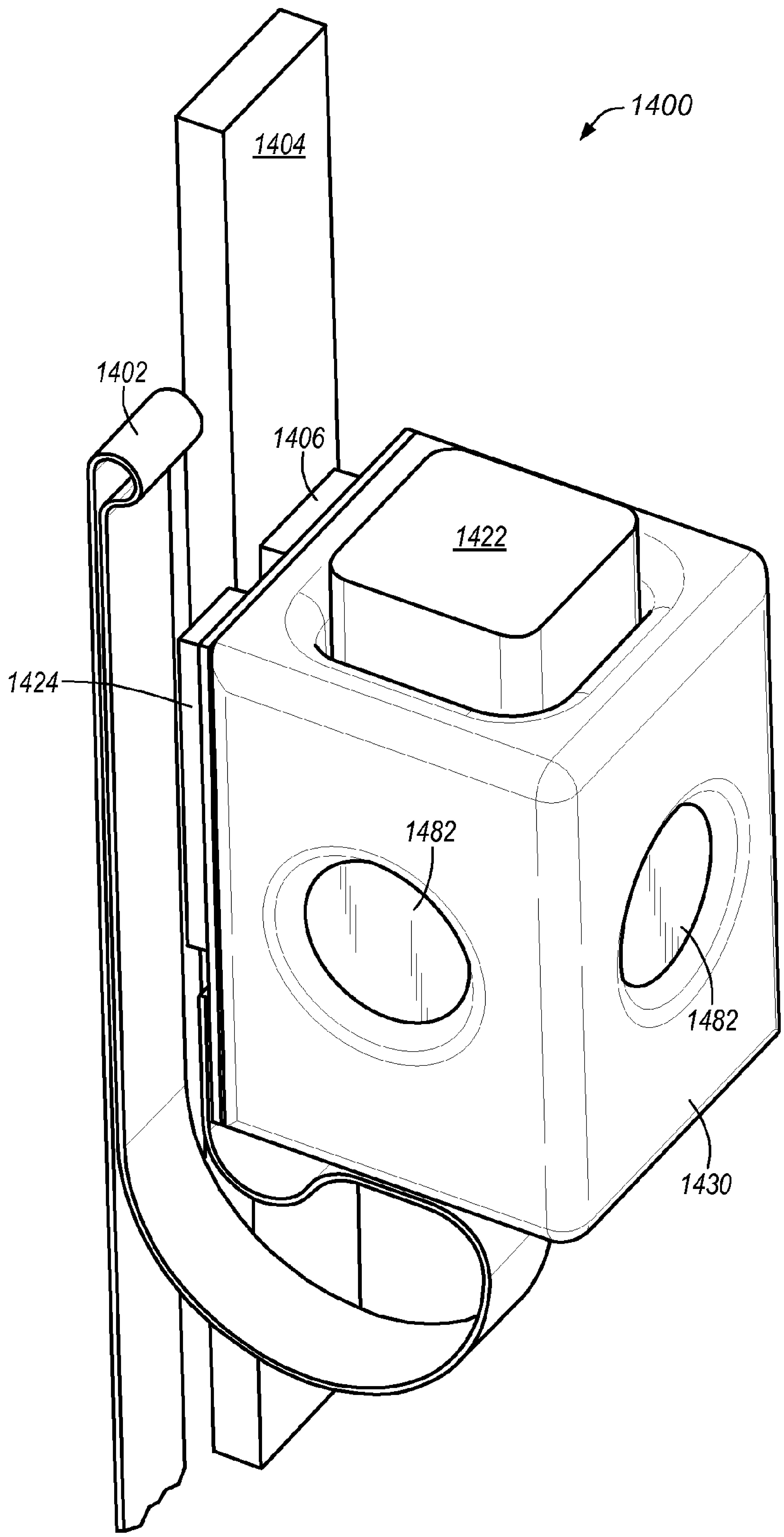


FIG. 14

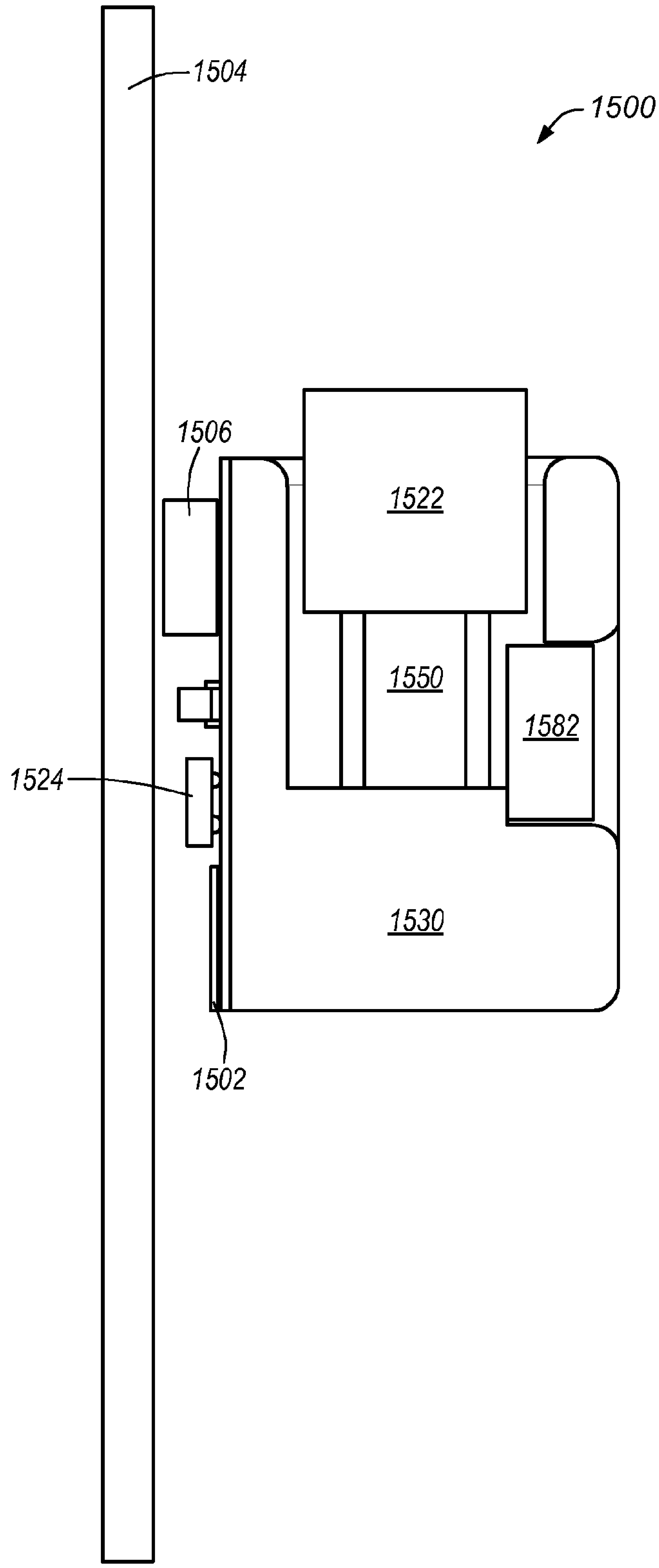


FIG. 15

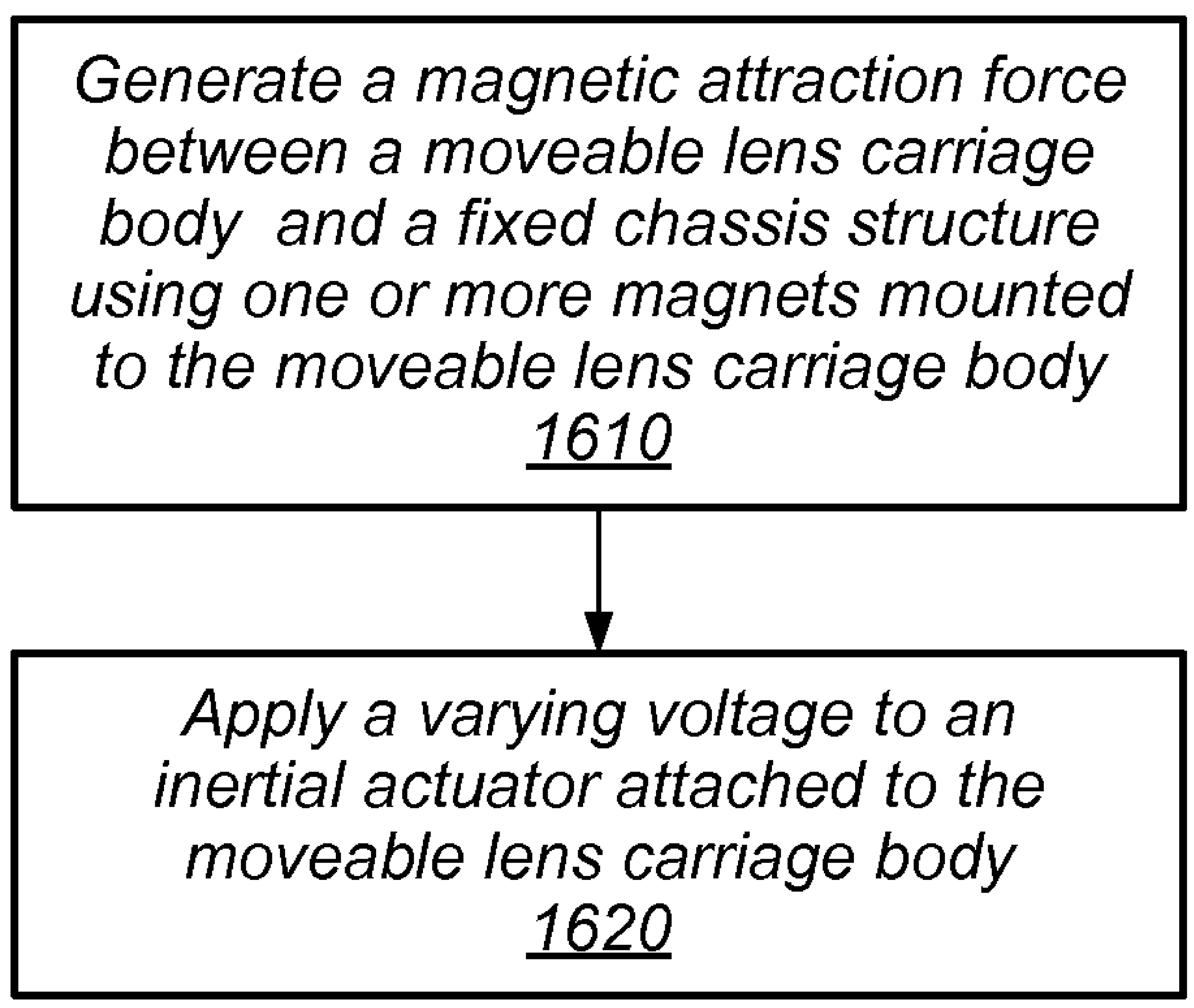

Generate a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure using one or more magnets mounted to the moveable lens carriage body
1610
Apply a varying voltage to an inertial actuator attached to the moveable lens carriage body
1620

FIG. 16

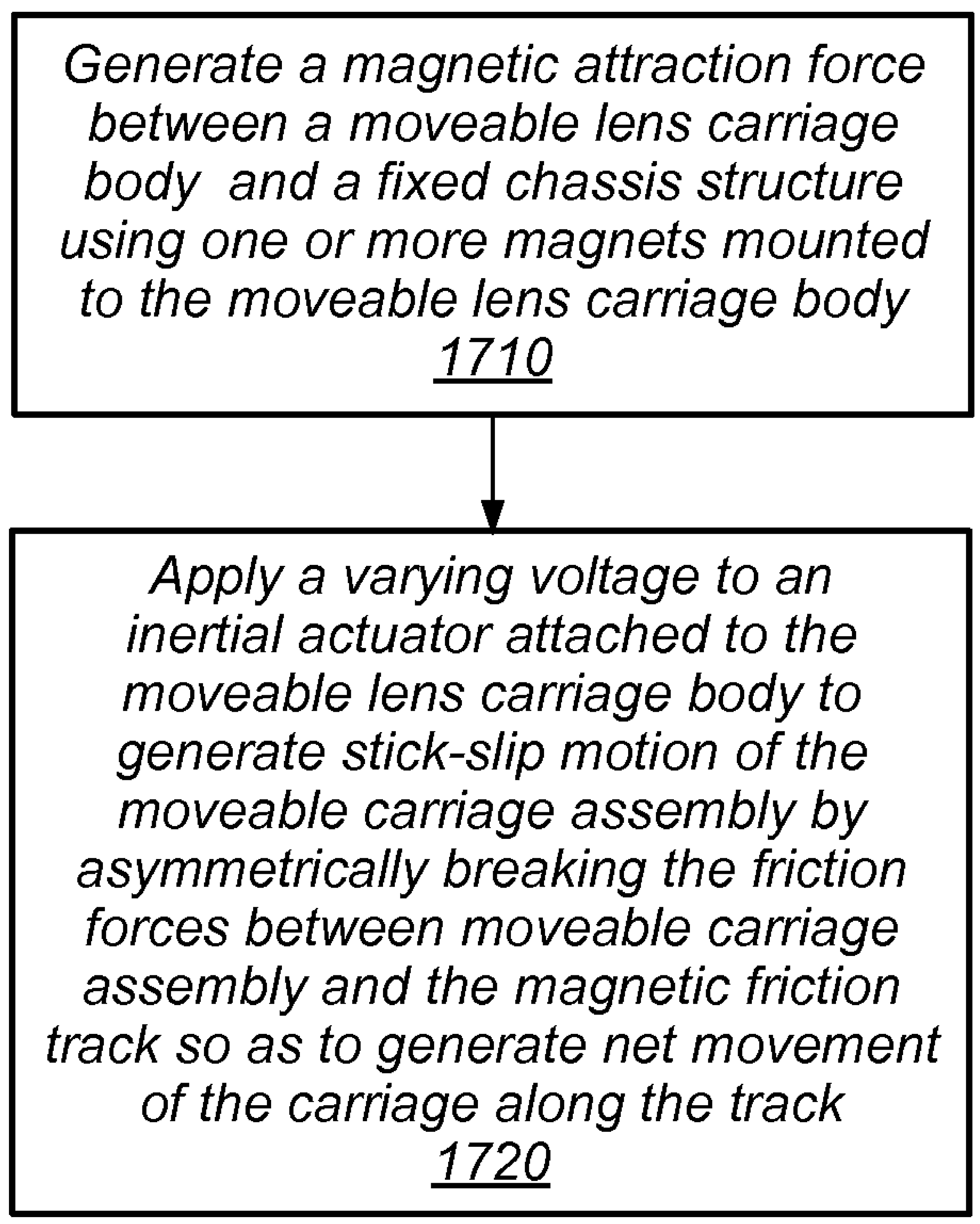

Generate a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure using one or more magnets mounted to the moveable lens carriage body
1710
Apply a varying voltage to an inertial actuator attached to the moveable lens carriage body to generate stick-slip motion of the moveable carriage assembly by asymmetrically breaking the friction forces between moveable carriage assembly and the magnetic friction track so as to generate net movement of the carriage along the track
1720

FIG. 17

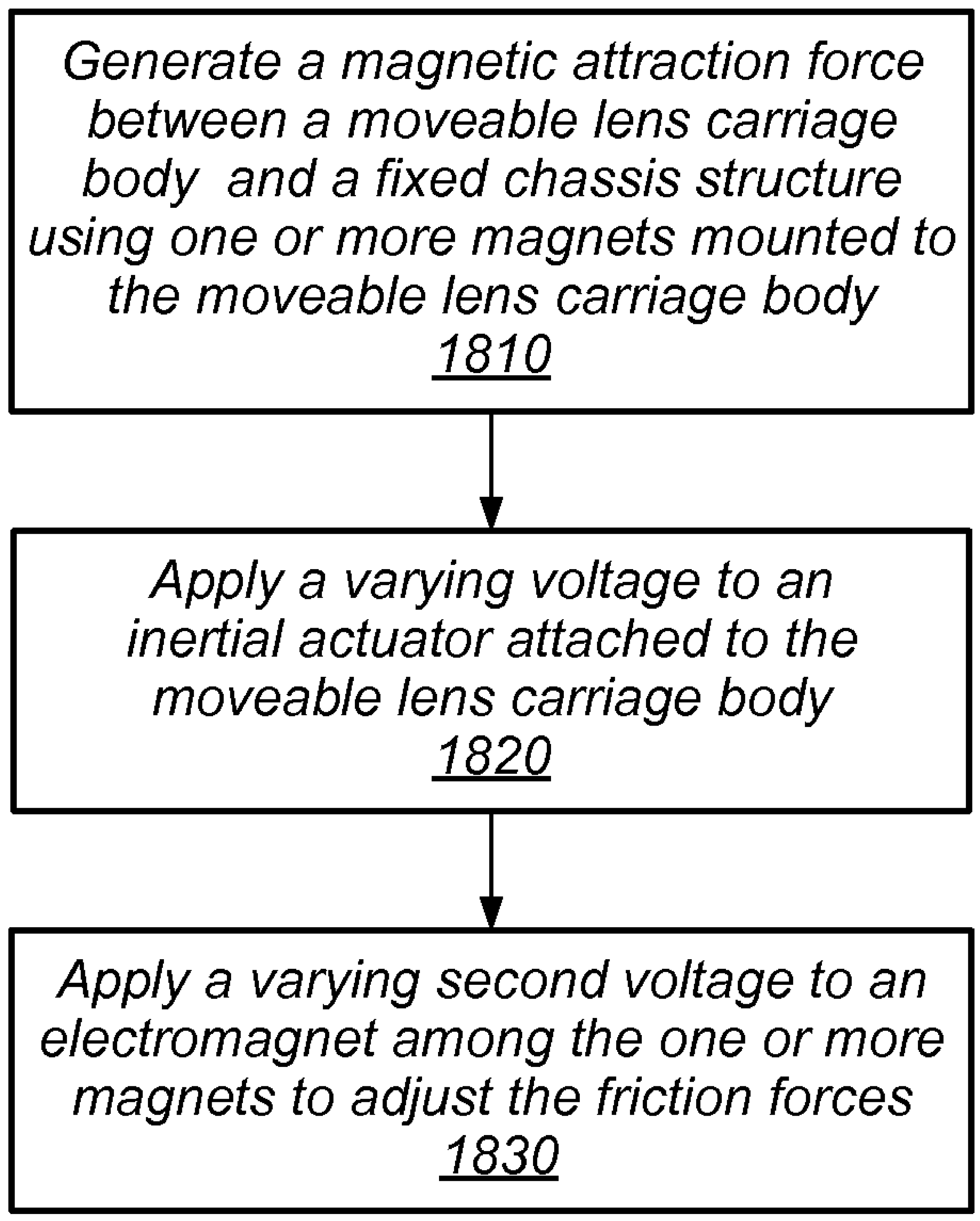

Generate a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure using one or more magnets mounted to the moveable lens carriage body 1810
Apply a varying voltage to an inertial actuator attached to the moveable lens carriage body 1820
Apply a varying second voltage to an electromagnet among the one or more magnets to adjust the friction forces 1830

FIG. 18

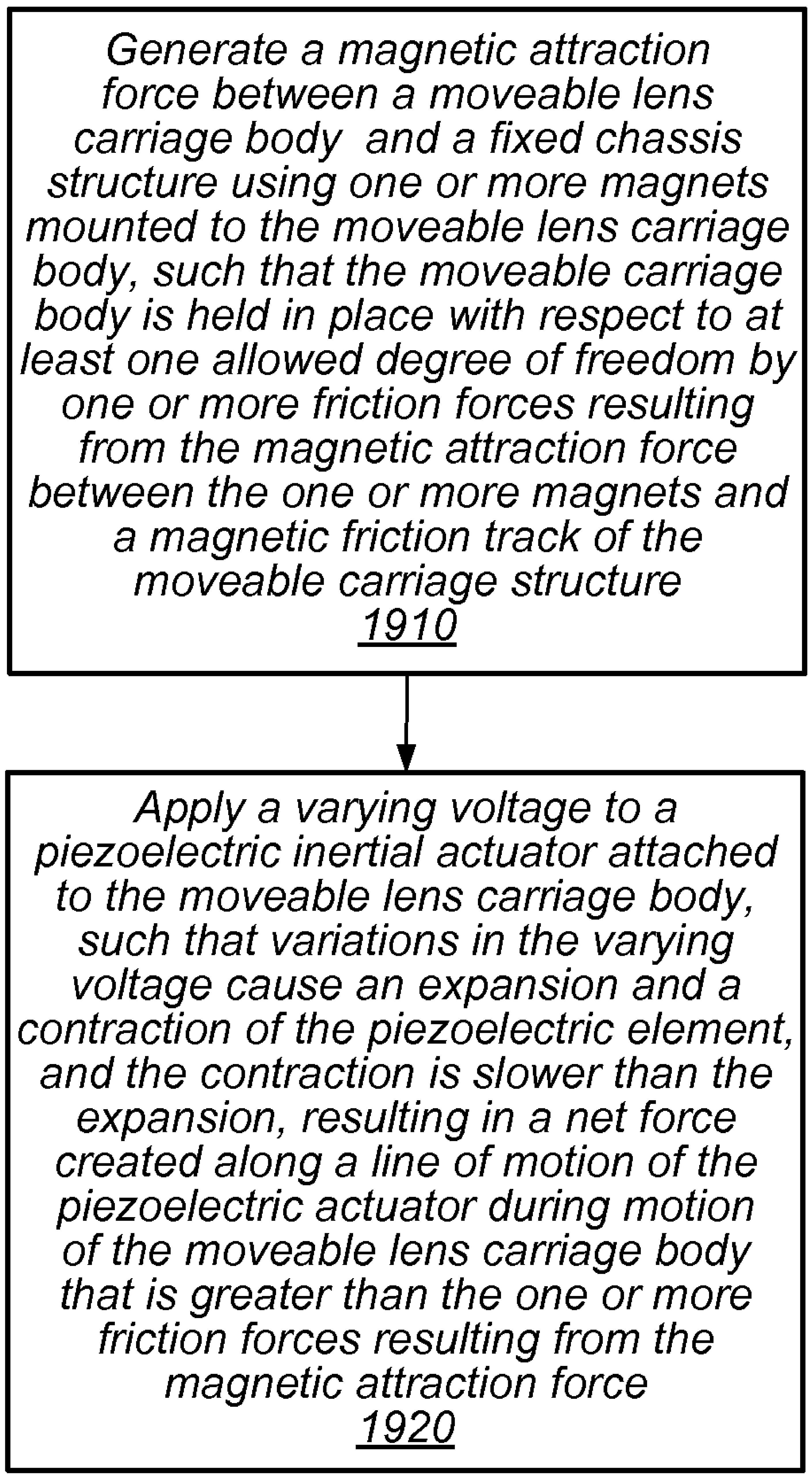

Generate a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure using one or more magnets mounted to the moveable lens carriage body, such that the moveable carriage body is held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force between the one or more magnets and a magnetic friction track of the moveable carriage structure
1910
Apply a varying voltage to a piezoelectric inertial actuator attached to the moveable lens carriage body, such that variations in the varying voltage cause an expansion and a contraction of the piezoelectric element, and the contraction is slower than the expansion, resulting in a net force created along a line of motion of the piezoelectric actuator during motion of the moveable lens carriage body that is greater than the one or more friction forces resulting from the magnetic attraction force
1920

FIG. 19

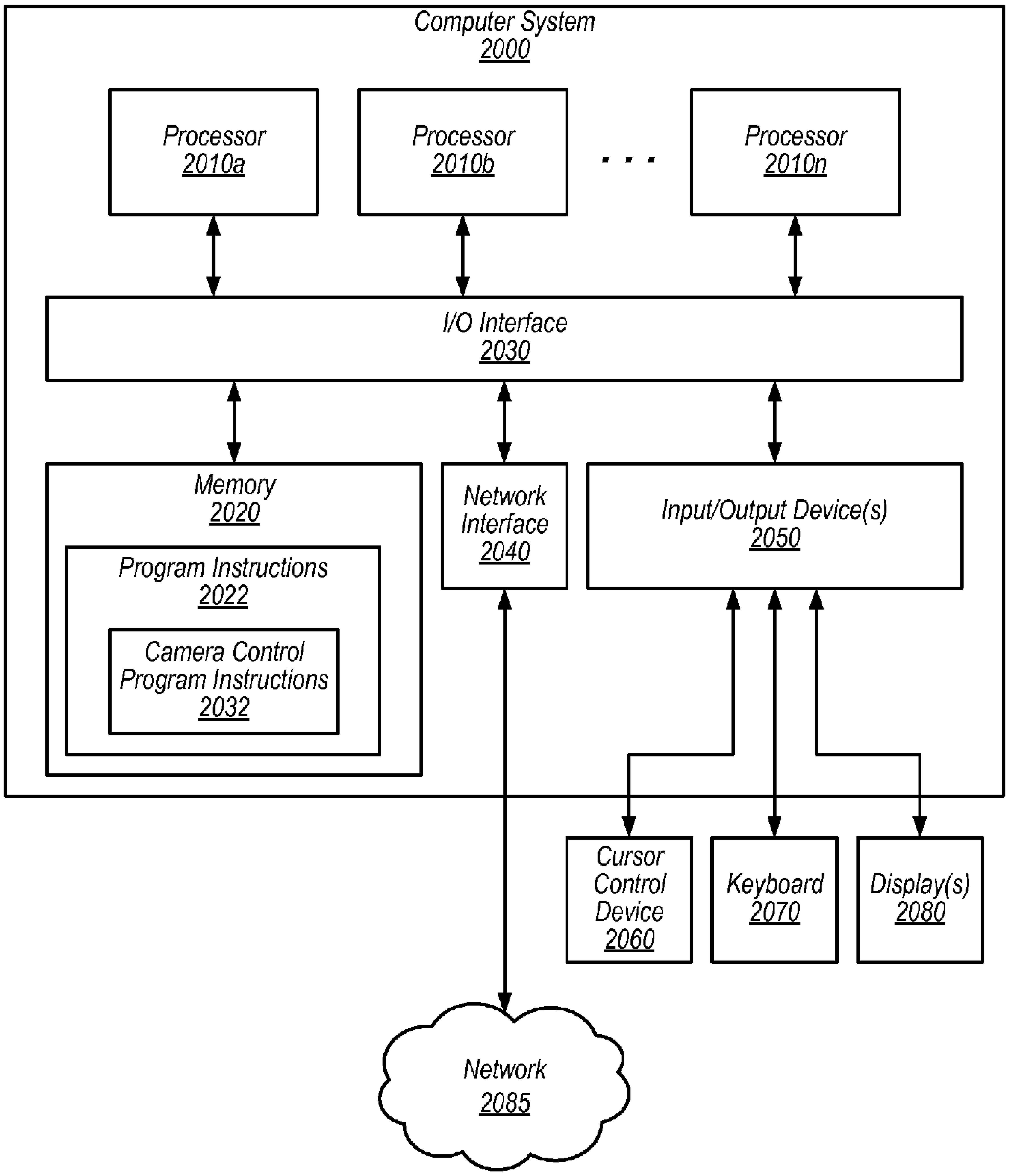

Computer System
2000
Processor
2010a
Processor
2010b
Processor
2010n
I/O Interface
2030
Memory
2020
Program Instructions
2022
Camera Control
Program Instructions
2032
Network
Interface
2040
Input/Output Device(s)
2050
Cursor
Control
Device
2060
Keyboard
2070
Display(s)
2080
Network
2085

FIG. 20

MINIATURE CAMERA ZOOM ACTUATOR WITH MAGNET-INDUCED FRICTION

This application claims benefit of priority to U.S. Provisional Patent Application Ser. No. 62/113,199, filed Feb. 6, 2015, which is hereby incorporated by reference in its entirety.

BACKGROUND

Technical Field

This disclosure relates generally to control of the motion of camera components. More specifically, this disclosure relates to an actuator for a zoom lens in a miniature camera.

Description of the Related Art

Miniature cameras are typically used in mobile devices such as cellphones. In such devices, space is held to be at a premium and every effort is made to minimize the camera size. A zoom lens is a lens where the lens elements can be moved relative to one another to change the focal length of the lens. In doing so, this changes the field of view of the lens. In addition, such a lens is most typically required to adjust focus for different object distances. Many different configurations of zoom lens are possible. However, for a typical optical zoom lens, there are at least two lens groups that move independently of each other along the optical axis relative to the image sensor, but in a relational manner to each other. There are additionally typically further lens groups that remain stationary relative to the image sensor.

For large digital stills cameras (DSCs), such relational movements are often achieved by moving one intermediate component, such as a cylinder disposed around the lens that rotates about the optical axis. The cylinder may then has plural grooves on its inner surface to act as cam profiles, at least one groove for each moving lens group. In this way the rotation of the cylinder with a single actuator can achieve the controlled relational movement between different lens groups relative to the image sensor. Such mechanisms work well for DSCs, but are not suited to miniature cameras for several reasons. The most important reasons include manufacturing tolerances and associated clearances, and parasitic frictions and forces, and size constraints. For miniature cameras, the positional tolerances required for placing the lens groups are extremely tight; of the order of 10 um. This includes factors such as relative tilt between the lens groups, and the decenter relative to the nominal optical axis.

Unfortunately, for such precision mechanisms, manufacturing tolerances do not scale with size, and so a decenter error caused by a clearance between cam groove and pin follower on the lens group may be acceptable for a larger DSC, but unacceptable for a miniature camera.

SUMMARY OF EMBODIMENTS

Some embodiments provide a zoom actuator system. Some embodiments include a fixed chassis structure and a moveable carriage body carrying one or more lenses. The fixed chassis structure includes a magnetic friction track. The moveable carriage body carries one or more lenses. An electrically-controllable magnet is mounted to the moveable carriage body for generating a magnetic attraction force between the magnet and the magnetic friction track. The moveable carriage body is movably mounted to the chassis to allow movement along an optical axis through the one or more lenses. An inertial actuator is mounted to the moveable carriage body in an alignment such that the axis of motion of the actuator is parallel to the optical axis through the one or more lenses. The moveable carriage body is held in place with respect to the at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a block diagram of a portable multifunction device with a camera in accordance with some embodiments.

FIG. **2** depicts a portable multifunction device having a camera in accordance with some embodiments.

FIG. **3** depicts schematic operation of an inertial actuator, according to some embodiments.

FIG. **4** illustrates schematic operation of an inertial actuator, according to some embodiments.

FIG. **5** illustrates a long-throw actuator assembled with its housing, according to some embodiments.

FIG. **6** depicts a long-throw actuator assembled with its housing, according to some embodiments.

FIG. **7** illustrates a cutaway view of a long-throw actuator assembled with its housing, according to some embodiments.

FIG. **8** depicts an actuator carriage without its housing, according to some embodiments.

FIG. **9** illustrates carriage construction and connection features, according to some embodiments.

FIG. **10** depicts a carriage connector, according to some embodiments.

FIG. **11** depicts a carriage and connector, according to some embodiments.

FIG. **12** depicts a carriage and connector, according to some embodiments.

FIG. **13** illustrates a long-throw actuator assembled with its housing, according to some embodiments.

FIG. **14** depicts a carriage and connector, according to some embodiments.

FIG. **15** illustrates a cutaway view of a long-throw actuator assembled with its housing, according to some embodiments.

FIG. **16** is a flowchart of a method for operating a zoom actuator, according to one embodiment.

FIG. **17** is a flowchart of a method for operating a zoom actuator, according to one embodiment.

FIG. **18** is a flowchart of a method for operating a zoom actuator, according to one embodiment.

FIG. **19** is a flowchart of a method for operating a zoom actuator, according to one embodiment.

FIG. **20** illustrates an example computer system configured to implement aspects of the system and method for camera control, according to some embodiments.

This specification includes references to "one embodiment" or "an embodiment." The appearances of the phrases "in one embodiment" or "in an embodiment" do not necessarily refer to the same embodiment. Particular features, structures, or characteristics may be combined in any suitable manner consistent with this disclosure.

"Comprising." This term is open-ended. As used in the appended claims, this term does not foreclose additional structure or steps. Consider a claim that recites: "An apparatus comprising one or more processor units . . . ." Such a claim does not foreclose the apparatus from including additional components (e.g., a network interface unit, graphics circuitry, etc.).

"Configured To." Various units, circuits, or other components may be described or claimed as "configured to" perform a task or tasks. In such contexts, "configured to" is used to connote structure by indicating that the units/circuits/components include structure (e.g., circuitry) that performs those task or tasks during operation. As such, the unit/circuit/component can be the to be configured to perform the task even when the specified unit/circuit/component is not currently operational (e.g., is not on). The units/circuits/components used with the "configured to" language include hardware—for example, circuits, memory storing program instructions executable to implement the operation, etc. Reciting that a unit/circuit/component is "configured to" perform one or more tasks is expressly intended not to invoke 35 U.S.C. §112, sixth paragraph, for that unit/circuit/component. Additionally, "configured to" can include generic structure (e.g., generic circuitry) that is manipulated by software and/or firmware (e.g., an FPGA or a general-purpose processor executing software) to operate in manner that is capable of performing the task(s) at issue. "Configure to" may also include adapting a manufacturing process (e.g., a semiconductor fabrication facility) to fabricate devices (e.g., integrated circuits) that are adapted to implement or perform one or more tasks.

"First," "Second," etc. As used herein, these terms are used as labels for nouns that they precede, and do not imply any type of ordering (e.g., spatial, temporal, logical, etc.). For example, a buffer circuit may be described herein as performing write operations for "first" and "second" values. The terms "first" and "second" do not necessarily imply that the first value must be written before the second value.

"Based On." As used herein, this term is used to describe one or more factors that affect a determination. This term does not foreclose additional factors that may affect a determination. That is, a determination may be solely based on those factors or based, at least in part, on those factors. Consider the phrase "determine A based on B." While in this case, B is a factor that affects the determination of A, such a phrase does not foreclose the determination of A from also being based on C. In other instances, A may be determined based solely on B.

DETAILED DESCRIPTION

Introduction to Zoom Actuators

Some embodiments provide a zoom actuator system. Some embodiments include a fixed chassis structure and a moveable carriage body. The moveable carriage body carries one or more lenses. The moveable carriage body is movably mounted to the chassis structure so as to limit a plurality of degrees of freedom of movement of the moveable carriage body but to allow movement along an optical axis through the one or more lenses. An inertial actuator is mounted to the moveable carriage body in an alignment such that the axis of motion of the actuator is parallel to at least one allowed degree of freedom. The moveable carriage body is held in place with respect to the at least one allowed degree of freedom by one or more magnetically-induced friction forces received at one or more mechanical contacts (called datum contact surfaces) with the chassis structure. The inertial actuator is actionable to overcome the friction forces, and an inertial mass is mounted to the inertial actuator on a side opposite the carriage body.

In some embodiments, the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit, which in some embodiments coils behind the actuator. Some embodiments include a driver circuit mounted on the moveable carriage body. The moveable carriage body receives power and control signals for the driver circuit to the inertial actuator through a flexible printed circuit. Some embodiments include a driver circuit mounted on the moveable carriage body, and a position sensor, mounted on the moveable carriage body, for determining a position of the moveable carriage body. In some embodiments, the position sensor is connected to the driver circuit for reporting position information to the driver circuit.

In some embodiments, the inertial actuator includes a piezoelectric actuator. In some embodiments, the moveable carriage body contacts the chassis along multiple magnetic tracks inside a non-magnetic or less magnetic chassis case. The system further includes one or more electromagnets to the moveable carriage body to generate a contact force at the one or more magnetic material tracks so as to generate a friction force between the moveable carriage body and the multiple magnetic tracks. Some embodiments further include a driver circuit mounted on the moveable carriage body, and a magnetic (Hall) position sensor, mounted on the moveable carriage body, for determining a position of the moveable carriage body based on magnetic fields experienced by the position sensor.

Some embodiments include a long-throw actuator including a carriage moving along a track, which is constrained to substantially slide along the track without parasitic tilting motion. In some embodiments, a piezo actuator is mounted onto the moving carriage for whirring a separate inertial mass that mounted to the other end of the piezo for inertial actuation. In some embodiments, the carriage incorporates at least one magnet that is attracted to the track, so as to generate contact forces that work to maintain contact between the Carriage and track, which as a result generates friction forces between the carriage and the track, thereby resisting the carriage slipping along the track. In some embodiments, during operation electrical drive signals are applied to the piezo so as to generate cyclical inertial forces to the carriage so as to generate stick-slip motion of the carriage by asymmetrically breaking the friction forces between carriage and track, so as to generate net movement of the carriage along the track.

In some embodiments, two magnets are embedded in the generally non-magnetic track carriage, each predominantly attracting the carriage to different datum surfaces of the track, so as to effectively constrain the carriage motion to one degree of freedom along the track.

In some embodiments, the carriage does not touch the can or carriage at locations other than the two datum surfaces. In some embodiments, the track datum surfaces are flat and orthogonal to each other. In some embodiments, an electrical conduit is provided to route electrical signals to the moving carriage. In some embodiments, the operational portion of said conduit can be approximated in section to a J shape when the carriage is at one end of travel, with the end of the curved region of the J attached to the carriage, and the end of the straight region of the J acting as a fixed anchor. In some embodiments, the motion of the carriage is parallel to the straight portion of the J and the carriage moves away from its end of travel position in the upwards direction, as defined by the a J.

Some embodiments include a fixed chassis structure and a moveable lens carriage. In some embodiments, the fixed chassis structure includes a magnetic friction track. In some embodiments, the moveable carriage body carries one or more lenses. In some embodiments, the one or more magnets is mounted to the moveable carriage body. In some embodiments, the moveable carriage body is movably mounted to the chassis to allow movement along an optical axis through the one or more lenses. In some embodiments, an inertial actuator is mounted to the moveable carriage body in an alignment such that the axis of motion of the actuator is parallel to the optical axis through the one or more lenses. In some embodiments, the moveable carriage body is held in place with respect to the at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force.

In some embodiments, the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit configured to coil behind and unwind beneath the moveable carriage body during movement. In some embodiments, a second inertial actuator is mounted to the moveable carriage body in an alignment such that the axis of motion of the second inertial actuator is not parallel to the optical axis through the one or more lenses.

In some embodiments, the moveable carriage body includes one or more datum surfaces. In some embodiments, the datum surfaces serve as points of frictional contact between the moveable carriage and magnetic friction track. In some embodiments, the moveable carriage does not touch the fixed chassis structure except at the points of contact between the datum surfaces and the magnetic friction track.

In some embodiments, the fixed chassis structure includes an external housing of non-magnetic material. In some embodiments, the magnetic friction track includes a strip of magnetic material mounted inside an enclosure formed by the fixed chassis structure.

Some embodiments include a method for controlling the position of a camera component. In some embodiments, the method includes generating a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure using one or more magnets mounted to the moveable lens carriage body. In some embodiments, the moveable carriage body is held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force between the one or more magnets and a magnetic friction track of the moveable carriage structure. In some embodiments, the method includes applying a varying voltage to an inertial actuator attached to the moveable lens carriage body. In some embodiments, the inertial actuator includes a piezoelectric element, and variations in the varying voltage cause an expansion and a contraction of the piezoelectric element. In some embodiments, the contraction is slower than the expansion, such that a net force is created along a line of motion of the piezoelectric actuator, and during motion of the moveable lens carriage body, the net force is greater than the one or more friction forces resulting from the magnetic attraction force.

In some embodiments, the method further includes applying a varying second voltage to a second inertial actuator mounted to the moveable carriage body in an alignment such that the axis of motion of the second inertial actuator is not parallel to the optical axis through the one or more lenses.

In some embodiments, the applying a voltage to an inertial actuator attached to the moveable lens carriage body further includes generating stick-slip motion of the moveable carriage assembly by asymmetrically breaking the friction forces between moveable carriage assembly and the magnetic friction track so as to generate net movement of the carriage along the track.

In some embodiments, the generating the magnetic attraction force further includes generating a friction force at one or more datum surfaces of the moveable carriage body. In some embodiments, the datum surfaces serve as points of frictional contact between the moveable carriage and the magnetic friction track.

In some embodiments, the applying the voltage further includes driving the inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other.

In some embodiments, the applying a voltage further includes driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other such that, during at least a portion of the oscillatory motion, inertial forces generated by the inertial actuator exceed a magnetic friction of datum contact points between the moveable carriage body and the chassis structure to cause sliding in an allowed linear degree of freedom.

In some embodiments, generating the magnetic attraction force between the moveable lens carriage body and the fixed chassis structure by applying the first voltage to one or more electrically controllable magnets mounted to the moveable lens carriage body further includes attracting the moveable lens carriage body to different datum surfaces of the track, so as to effectively constrain a carriage motion of the moveable lens carriage body to one degree of freedom along the track.

Some embodiments include a non-transitory computer-readable storage medium storing program instructions. In some embodiments, the program instructions are computer-executable to implement measuring a position of a carriage relative to a fixed chassis structure, wherein the chassis carries one or more magnets for generating a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure.

In some embodiments, the program instructions are computer-executable to implement applying a varying voltage to an inertial actuator attached to the moveable lens carriage body to generate a net force. In some embodiments, variations in the varying first voltage cause an expansion and a contraction of a piezoelectric element along an optical axis of a lens of the moveable lens carriage body, and during motion of the moveable lens carriage body, the net force is greater than the one or more friction forces resulting from the magnetic attraction force.

In some embodiments, program instructions are computer-executable to implement applying a second voltage to a second inertial actuator mounted to the moveable carriage body in an alignment such that the axis of motion of the second inertial actuator is not parallel to the optical axis through the one or more lenses.

In some embodiments, program instructions computer-executable to implement generating a friction force at one or more datum surfaces of the moveable carriage body. In some embodiments, the datum surfaces serve as exclusive points of frictional contact between the moveable carriage and the magnetic friction track.

In some embodiments, the program instructions computer-executable to implement the applying a varying voltage to an inertial actuator attached to the moveable lens carriage body further include program instructions computer-executable to implement generating stick-slip motion of the moveable carriage assembly by asymmetrically breaking the friction forces between moveable carriage assembly and the magnetic friction track so as to generate net movement of the carriage along the track.

In some embodiments, the program instructions computer-executable to implement the applying the voltage further include program instructions computer-executable to implement driving the inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other.

In some embodiments, the program instructions computer-executable to implement the applying the voltage further include program instructions computer-executable to implement driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other such that, during at least a portion of the oscillatory motion, inertial forces generated by the inertial actuator exceed a magnetic friction of datum contact points between the moveable carriage body and the chassis structure to cause sliding in an allowed linear degree of freedom.

In some embodiments, the one or more magnets include one or more electrically controllable magnets, and the moveable carriage body receives power and control signals to the inertial actuator and the one or more magnets through a flexible printed circuit configured to coil behind and unwind beneath the moveable carriage body during movement.

In some embodiments, generating a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure from magnets mounted to the moveable lens carriage body. In some embodiments, the moveable carriage body is controllably held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force between the one or more magnets and a magnetic friction track of the moveable carriage structure further includes generating a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure by applying a second voltage to one or more electrically controllable magnets mounted to the moveable lens carriage body. In some embodiments, the moveable carriage body is controllably held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force between the one or more electrically controllable magnets and a magnetic friction track of the moveable carriage structure.

Some embodiments include a method for controlling camera components. In some embodiments, the method includes applying a first voltage to an inertial actuator attached to a moveable lens carriage body. The inertial actuator is a piezoelectric element, and the first voltage causes an expansion of the piezoelectric element. In some embodiments, the method further includes applying a second voltage to the inertial actuator attached to a moveable lens carriage body. The second voltage causes a contraction of the piezoelectric element, and the contraction is slower than the expansion.

In some embodiments, the method further includes applying a third voltage to an inertial actuator attached to a moveable lens carriage body. The third voltage causes a contraction of the piezoelectric element. In some embodiments, the method further includes applying a fourth voltage to the inertial actuator attached to a moveable lens carriage body. The fourth voltage causes an expansion of the piezoelectric element, and the expansion is slower than the contraction.

In some embodiments, the method further includes measuring a position of the moveable lens carriage body using a magnetic sensor attached to the moveable lens carriage body. In some embodiments the applying a first voltage and the applying a second voltage further comprise driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other.

In some embodiments, the applying a first voltage and the applying a second voltage further comprise driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other such that, during at least a portion of the oscillatory motion, inertial forces generated by the inertial actuator exceed a static friction of contact points between the moveable carriage body and the chassis structure to cause sliding in an allowed linear degree of freedom.

In some embodiments, the applying a first voltage and the applying a second voltage further comprise driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal having a sawtooth waveform.

In some embodiments, the method further includes driving an inertial actuator attached to a second moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other such that the second moveable lens carriage body moves with respect to the first moveable lens carriage body.

Some embodiments may include camera module including a means for applying a first voltage to an inertial actuator attached to a moveable lens carriage body, and applying a second voltage to the inertial actuator attached to a moveable lens carriage body, as described herein. The camera module may in some embodiments be implemented by a non-transitory, computer-readable storage medium and one or more processors (e.g., CPUs and/or GPUs) of a computing apparatus. The computer-readable storage medium may store program instructions executable by the one or more processors to cause the computing apparatus to perform applying a first voltage to an inertial actuator attached to a moveable lens carriage body, and applying a second voltage to the inertial actuator attached to a moveable lens carriage body, as described herein. Other embodiments of the non-uniform camera module may be at least partially implemented by hardware circuitry and/or firmware stored, for example, in a non-volatile memory.

Some embodiments provide a zoom actuator system. In some embodiments, a moving body slides on a fixed chassis structure. In some embodiments, the fixed chassis structure substantially limits the motion of the moving body to one linear degree of freedom.

In some embodiments, the moving body contacts the chassis at multiple discrete points so as to constrain the motion. In some embodiments, at least one of these contact points is forced into contact with the track based on a magnetic force from the moving body so as to generate a contact force at others of the contact points, so as to generate a sufficient friction force to both prevent any unwanted sliding at the contact points. In some embodiments, there is mounted on the moving body an inertial actuator, which when actuated with appropriate electrical signals can generate inertial loads that exceed the magnetically-generated friction of the contacts points and yield motion in the allowed linear degree(s) of freedom.

In some embodiments, the inertial actuator is driven with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other, and during at least a portion of the oscillatory motion, the inertial forces exceed the static friction of the contact points and cause sliding in the allowed linear degree of freedom.

In some embodiments, multiple such oscillatory cycles, in combination, yield a net motion of the moving body in one direction relative to the chassis, and the reverse motion can be achieved by appropriately altering the asymmetric electrical signal.

In some embodiments, a programmable driver circuit for the inertial actuator is also mounted on the moving body. In some embodiments, connections to power the driver circuit are provided through the multiple electrical contacts via the contact points, at least two include a positive power terminal and a negative power terminal to power and deliver digital commands to the driver circuit so as to determine how to move the inertial actuator.

In some embodiments, the moving body includes a lens group as part of a lens system, and the allowed linear degree of freedom is parallel to the lens optical axis. In some embodiments, the actuator system is used to appropriately move a lens groups in a zoom lens. In some embodiments, multiple moving bodies move along the same tracks in the same chassis. In some embodiments position sensors are incorporated on each of the multiple moving bodies, so as to measure the position of each moving body in the chassis. In some embodiments, the position sensors are magnetic. In other embodiments, the position sensors are capacitive.

In some embodiments, a patterned trace forms part of the chassis, and interacts with a magnetic sensor on the moving body, such that the magnetic field at the sensor is measured as the moving body moves in the chassis, and the current and historical measurements can be used to assess position of the moving body.

In some embodiments, a patterned conductive trace forms part of the chassis, and interacts with a conductive plate on the moving body to create a capacitance sensor, such that the capacitance of the sensor is measured as the moving body moves in the chassis, and the current and historical measurements can be used to assess position of the moving body.

In some embodiments, a zoom actuator system includes a fixed chassis structure and a moving carriage body. In some embodiments, the moving carriage body carries one or more lenses. In some embodiments, the moving carriage body is movably mounted to the chassis structure so as to limit degrees of freedom of movement of the moving carriage body to one or more allowed degrees of freedom. An inertial actuator is mounted to the moving carriage body in an alignment such that the axis of motion of the actuator is parallel to at least one of the one or more allowed degrees of freedom. An inertial mass is mounted to the inertial actuator on a side opposite the carriage body.

Some embodiments further include a driver circuit mounted on the moving carriage body, and a position sensor, mounted on the moving carriage body, for determining a position of the moving carriage body, such that the position sensor is connected to the driver circuit for reporting position information to the driver circuit. In some embodiments, the inertial actuator comprises a piezoelectric actuator.

In some embodiments, the moving carriage body contacts the chassis at datum surfaces of the moving carriage body to generate a friction force between the moving carriage body and the multiple conductive tracks as a result of magnetic force.

In some embodiments, the system further includes a driver circuit mounted on the moving carriage body, and a capacitive position sensor, mounted on the moving carriage body, for determining a position of the moving carriage body based on a plate capacitance between a plate of the position sensor and a metal pattern track on the chassis.

Some embodiments further include a method for operating a zoom actuator. In some embodiments, the method includes applying a first voltage to an inertial actuator attached to a moveable lens carriage body. In some embodiments, the inertial actuator is a piezoelectric element, and the first voltage causes an expansion of the piezoelectric element. In some embodiments, the method further includes applying a second voltage to the inertial actuator attached to a moveable lens carriage body. In some embodiments, the second voltage causes a contraction of the piezoelectric element, and the contraction is slower than the expansion.

In some embodiments, the method further includes applying a third voltage to an inertial actuator attached to a moveable lens carriage body. In some embodiments, the third voltage causes a contraction of the piezoelectric element. In some embodiments, the method further includes applying a fourth voltage to the inertial actuator attached to a moveable lens carriage body. The fourth voltage causes an expansion of the piezoelectric element, and the expansion is slower than the contraction.

In some embodiments, the method further includes measuring a position of the moveable lens carriage body using a sensor attached to the moveable lens carriage body. In some embodiments, the applying a first voltage and the applying a second voltage further include driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other.

In some embodiments, the applying a first voltage and the applying a second voltage further include driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other such that, during at least a portion of the oscillatory motion, inertial forces generated by the inertial actuator exceed a magnetically-induced friction between the moving carriage body and the chassis structure to cause sliding in an allowed linear degree of freedom.

In some embodiments, the applying a first voltage and the applying a second voltage further include driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal having a sawtooth waveform.

In some embodiments, the method further includes driving an inertial actuator attached to a second moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other such that the second moveable lens carriage body moves with respect to the first moveable lens carriage body.

Some embodiments include a means for controlling a zoom actuator of a camera, as described herein. For example, a camera control module may drive an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other, as described herein. The camera control module may in some embodiments be implemented by a non-transitory, computer-readable storage medium and one or more processors (e.g., CPUs and/or GPUs) of a computing apparatus. The computer-readable storage medium may store program instructions executable by the one or more processors to cause the computing apparatus to perform driving an inertial actuator attached to the moveable lens carriage body with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other, as described herein. Other embodiments of the camera control module may be at least partially implemented by hardware circuitry and/or firmware stored, for example, in a non-volatile memory.

Some embodiments include an actuator system, which includes a moveable carriage that slides along surfaces of a fixed support structure. In some embodiments the contact surfaces between the moveable carriage and the fixed support structure collectively substantially constrain five degrees of freedom of motion of the moveable carriage, and the remaining sixth degree of freedom represents linear motion of the moveable carriage along an axis relative to the fixed support structure. In some embodiments the motion is limited by friction between the moveable carriage and the fixed support structure that is generated as a result of magnetic force. In some embodiments the contact forces that generate the friction forces are themselves generated by magnets or electromagnets mounted to the moveable carriage that contacts a further surface of the fixed support structure, and the motion of the moveable carriage relative to the fixed support structure is controlled by the operation of an inertial actuator mounted on the moveable carriage. In some embodiments, the inertial actuator includes a linear actuator with direction of motion parallel to the movement axis, fixed at one end to the moveable carriage and at the other to an inertial mass.

In some embodiments, the inertial actuator is driven with an asymmetric oscillatory electrical signal so that in one part of the cycle the inertial acceleration of the moveable carriage is higher than in another, and during at least a portion of the oscillatory motion, the inertial forces exceed the static friction of the frictional contacts between the moveable carriage and the fixed support structure and cause sliding in the allowed linear degree of freedom. In combination, multiple such oscillatory cycles yield a net motion of the moveable carriage in one direction relative to the fixed support structure, and the reverse motion can be achieved by appropriately altering the asymmetric electrical signal.

In some embodiments, the programmable driver circuit for the inertial actuator is also mounted on the moveable carriage, and at least four electrical signals are supplied to the moveable carriage, two being electrical power terminals and two being communication terminals to command a desired motion.

In some embodiments, multiple moveable carriages and inertial actuators operate independently along the same guide surfaces of the fixed support structure. In some embodiments, the moveable carriage is used to move one or more optical elements of a miniature camera, such that the axis of motion of the moveable carriage is parallel to the optical axis of the one or more optical elements.

In some embodiments, the inertial actuator includes a piezoelectric element that represents the linear actuator attached to an inertial mass. In some embodiments, capacitive position sensors detect the capacitance between an electrode mounted on the moveable carriage and a patterned electrode mounted on the fixed support structure in such a way that the capacitance varies depending on the position of the moveable carriage.

In some embodiments, the electrode pattern forms an oscillatory pattern along the direction of motion, such that the measured capacitance oscillates as the moveable carriage moves along the axis of motion in a given direction, so that a coarse measure of position from a given home position is determined by counting the number of oscillatory cycles, and a fine measure of position is determined by the actual measured capacitance within one oscillatory cycle of capacitance.

Some embodiments include an actuator system for a moveable carriage that slides along surfaces of a fixed support structure. In some embodiments, the contact surfaces between the moveable carriage and the fixed support structure collectively substantially constrain up to five degrees of freedom of motion of the moveable carriage, and the remaining sixth degree of freedom represents linear motion of the moveable carriage along an axis relative to the fixed support structure. In some embodiments, the motion is limited by friction between the moveable carriage and the fixed support structure.

In some embodiments the contact forces that generate the friction forces are themselves generated by a magnetic portion of the moveable carriage that interacts with a further magnetic surface of the fixed support structure. In some embodiments, the motion of the moveable carriage relative to the fixed support structure is controlled by the operation of an inertial actuator mounted on the moveable carriage, which includes linear actuator with direction of motion parallel to the movement axis, fixed at one end to the moveable carriage and at the other to an inertial mass. In some embodiments, separate electrical connection means is provided to the moveable carriage to electrically drive the inertial actuator as appropriate to generate the desired motion.

In some embodiments, the inertial actuator is driven with an asymmetric oscillatory electrical signal so that in one part of the cycle the inertial acceleration of the moveable carriage is higher than in another, and during at least a portion of the oscillatory motion, the inertial forces exceed the static friction of the frictional contacts between the moveable carriage and the fixed support structure and cause sliding in the allowed linear degree of freedom. In combination, multiple such oscillatory cycles yield a net motion of the moveable carriage in one direction relative to the fixed support structure, and wherein the reverse motion can be achieved by appropriately altering the asymmetric electrical signal.

In some embodiments, the programmable driver circuit for the inertial actuator is also mounted on the moveable carriage, and at least four electrical signals are supplied to the moveable carriage, two being electrical power terminals and two being communication terminals to command a desired motion. In some embodiments, plural such moveable carriages and inertial actuators operate independently along the same guide surfaces of the fixed support structure.

In some embodiments, the moveable carriage is used to move one or more optical elements of a miniature camera, such that the axis of motion of the moveable carriage is parallel to the optical axis of the one or more optical elements. In some embodiments, the inertial actuator includes a piezoelectric element that is a linear actuator attached to an inertial mass.

In some embodiments, the one or more magnets include one or more electrically controllable magnets, and the moveable carriage body receives power and control signals to the inertial actuator and the one or more magnets through a flexible printed circuit configured to coil behind and unwind beneath the moveable carriage body during movement.

In some embodiments, the method further includes generating a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure from magnets mounted to the moveable lens carriage body. In some embodiments the moveable carriage body is controllably held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force between the one or more magnets and a magnetic friction track of the moveable carriage structure further includes

In some embodiments, the method further includes generating a magnetic attraction force between a moveable lens carriage body and a fixed chassis structure by applying a second voltage to one or more electrically controllable magnets mounted to the moveable lens carriage body. In some embodiments, the moveable carriage body is controllably held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force between the one or more electrically controllable magnets and a magnetic friction track of the moveable carriage structure.

Introduction to Piezoelectric Materials

The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry. The piezoelectric effect is a reversible process in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field). For example, lead zirconate titanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material.

A piezoelectric actuator converts an electrical signal into a precisely controlled physical displacement (stroke). If displacement is prevented, a useable force (blocking force) will develop. The precise movement control afforded by piezoelectric actuators is used to finely adjust machining tools, lenses, mirrors, or other equipment. Piezoelectric actuators are also used to control hydraulic valves, act as small-volume pumps or special-purpose motors, and in other applications requiring movement or force.

Multifunction Device

Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the present disclosure. However, it will be apparent to one of ordinary skill in the art that some embodiments may be practiced without these specific details. In other instances, well-known methods, procedures, components, circuits, and networks have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

It will also be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first contact could be termed a second contact, and, similarly, a second contact could be termed a first contact, without departing from the intended scope. The first contact and the second contact are both contacts, but they are not the same contact.

The terminology used in the description herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used in the description and the appended claims, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "includes," "including," "comprises," and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

As used herein, the term "if" may be construed to mean "when" or "upon" or "in response to determining" or "in response to detecting," depending on the context. Similarly, the phrase "if it is determined" or "if [a stated condition or event] is detected" may be construed to mean "upon determining" or "in response to determining" or "upon detecting [the stated condition or event]" or "in response to detecting [the stated condition or event]," depending on the context.

Embodiments of electronic devices, user interfaces for such devices, and associated processes for using such devices are described. In some embodiments, the device is a portable communications device, such as a mobile telephone, that also contains other functions, such as PDA and/or music player functions. Exemplary embodiments of portable multifunction devices include, without limitation, portable electronic devices, such as laptops or tablet computers with touch-sensitive surfaces (e.g., touch screen displays and/or touch pads), may also be used. It should also be understood that, in some embodiments, the device is not a portable communications device, but is a desktop computer with a camera. In some embodiments, the device is a gaming computer with orientation sensors (e.g., orientation sensors in a gaming controller). In other embodiments, the device is not a portable communications device, but is a camera.

The device typically supports a variety of applications, such as one or more of the following: a drawing application, a presentation application, a word processing application, a website creation application, a disk authoring application, a spreadsheet application, a gaming application, a telephone application, a video conferencing application, an e-mail application, an instant messaging application, a workout support application, a photo management application, a digital camera application, a digital video camera application, a web browsing application, a digital music player application, and/or a digital video player application.

Attention is now directed toward embodiments of portable devices with cameras. FIG. **1**A is a block diagram illustrating portable multifunction device **100** with camera **164** in accordance with some embodiments. Camera **164** is sometimes called an "optical sensor" for convenience, and may also be known as or called an optical sensor system or zoom camera system. Device **100** may include memory **102** (which may include one or more computer readable storage mediums), memory controller **122**, one or more processing units (CPU's) **120**, peripherals interface **118**, RF circuitry **108**, audio circuitry **110**, speaker **111**, touch-sensitive display system **112**, microphone **113**, input/output (I/O) subsystem **106**, other input or control devices **116**, and external port **124**. Device **100** may include one or more optical sensors **164**. These components may communicate over one or more communication buses or signal lines **103**.

It should be appreciated that device **100** is only one example of a portable multifunction device, and that device **100** may have more or fewer components than shown, may combine two or more components, or may have a different configuration or arrangement of the components. The various components shown in FIG. **1**A may be implemented in hardware, software, or a combination of hardware and software, including one or more signal processing and/or application specific integrated circuits.

Memory **102** may include high-speed random access memory and may also include non-volatile memory, such as one or more magnetic disk storage devices, flash memory devices, or other non-volatile solid-state memory devices. Access to memory **102** by other components of device **100**, such as CPU **120** and the peripherals interface **118**, may be controlled by memory controller **122**.

Peripherals interface **118** can be used to couple input and output peripherals of the device to CPU **120** and memory **102**. The one or more processors **120** run or execute various software programs and/or sets of instructions stored in memory **102** to perform various functions for device **100** and to process data.

In some embodiments, peripherals interface **118**, CPU **120**, and memory controller **122** may be implemented on a single chip, such as chip **104**. In some other embodiments, they may be implemented on separate chips.

RF (radio frequency) circuitry **108** receives and sends RF signals, also called electromagnetic signals. RF circuitry **108** converts electrical signals to/from electromagnetic signals and communicates with communications networks and other communications devices via the electromagnetic signals. RF circuitry **108** may include well-known circuitry for performing these functions, including but not limited to an antenna system, an RF transceiver, one or more amplifiers, a tuner, one or more oscillators, a digital signal processor, a CODEC chipset, a subscriber identity module (SIM) card, memory, and so forth. RF circuitry **108** may communicate with networks, such as the Internet, also referred to as the World Wide Web (WWW), an intranet and/or a wireless network, such as a cellular telephone network, a wireless local area network (LAN) and/or a metropolitan area network (MAN), and other devices by wireless communication. The wireless communication may use any of a variety of communications standards, protocols and technologies, including but not limited to Global System for Mobile Communications (GSM), Enhanced Data GSM Environment (EDGE), high-speed downlink packet access (HSDPA), high-speed uplink packet access (HSUPA), wideband code division multiple access (W-CDMA), code division multiple access (CDMA), time division multiple access (TDMA), Bluetooth, Wireless Fidelity (Wi-Fi) (e.g., IEEE 802.11a, IEEE 802.11b, IEEE 802.11g and/or IEEE 802.11n), voice over Internet Protocol (VoIP), Wi-MAX, a protocol for e-mail (e.g., Internet message access protocol (IMAP) and/or post office protocol (POP)), instant messaging (e.g., extensible messaging and presence protocol (XMPP), Session Initiation Protocol for Instant Messaging and Presence Leveraging Extensions (SIMPLE), Instant Messaging and Presence Service (IMPS)), and/or Short Message Service (SMS), or any other suitable communication protocol, including communication protocols not yet developed as of the filing date of this document.

Audio circuitry **110**, speaker **111**, and microphone **113** provide an audio interface between a user and device **100**. Audio circuitry **110** receives audio data from peripherals interface **118**, converts the audio data to an electrical signal, and transmits the electrical signal to speaker **111**. Speaker **111** converts the electrical signal to human-audible sound waves. Audio circuitry **110** also receives electrical signals converted by microphone **113** from sound waves. Audio circuitry **110** converts the electrical signal to audio data and transmits the audio data to peripherals interface **118** for processing. Audio data may be retrieved from and/or transmitted to memory **102** and/or RF circuitry **108** by peripherals interface **118**. In some embodiments, audio circuitry **110** also includes a headset jack (e.g., **212**, FIG. **2**). The headset jack provides an interface between audio circuitry **110** and removable audio input/output peripherals, such as output-only headphones or a headset with both output (e.g., a headphone for one or both ears) and input (e.g., a microphone).

I/O subsystem **106** couples input/output peripherals on device **100**, such as touch screen **112** and other input control devices **116**, to peripherals interface **118**. I/O subsystem **106** may include display controller **156** and one or more input controllers **160** for other input or control devices. The one or more input controllers **160** receive/send electrical signals from/to other input or control devices **116**. The other input control devices **116** may include physical buttons (e.g., push buttons, rocker buttons, etc.), dials, slider switches, joysticks, click wheels, and so forth. In some alternate embodiments, input controller(s) **160** may be coupled to any (or none) of the following: a keyboard, infrared port, USB port, and a pointer device such as a mouse. The one or more buttons (e.g., **208**, FIG. **2**) may include an up/down button for volume control of speaker **111** and/or microphone **113**. The one or more buttons may include a push button (e.g., **206**, FIG. **2**).

Touch-sensitive display **112** provides an input interface and an output interface between the device and a user. Display controller **156** receives and/or sends electrical signals from/to touch screen **112**. Touch screen **112** displays visual output to the user. The visual output may include graphics, text, icons, video, and any combination thereof (collectively termed "graphics"). In some embodiments, some or all of the visual output may correspond to user-interface objects.

Touch screen **112** has a touch-sensitive surface, sensor or set of sensors that accepts input from the user based on haptic and/or tactile contact. Touch screen **112** and display controller **156** (along with any associated modules and/or sets of instructions in memory **102**) detect contact (and any movement or breaking of the contact) on touch screen **112** and converts the detected contact into interaction with user-interface objects (e.g., one or more soft keys, icons, web pages or images) that are displayed on touch screen **112**. In an exemplary embodiment, a point of contact between touch screen **112** and the user corresponds to a finger of the user.

In some embodiments, in addition to the touch screen, device **100** may include a touchpad (not shown) for activating or deactivating particular functions. In some embodiments, the touchpad is a touch-sensitive area of the device that, unlike the touch screen, does not display visual output. The touchpad may be a touch-sensitive surface that is separate from touch screen **112** or an extension of the touch-sensitive surface formed by the touch screen.

Device **100** also includes power system **162** for powering the various components. Power system **162** may include a power management system, one or more power sources (e.g., battery, alternating current (AC)), a recharging system, a power failure detection circuit, a power converter or inverter, a power status indicator (e.g., a light-emitting diode (LED)) and any other components associated with the generation, management and distribution of power in portable devices.

Device **100** may also include one or more optical sensors or cameras **164**, which may include zoom actuators as described herein. FIG. **1**A shows an optical sensor coupled to optical sensor controller **158** in I/O subsystem **106**.

Optical sensor **164** may include charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) phototransistors.

Optical sensor **164** receives light from the environment, projected through one or more lens, and converts the light to data representing an image. In conjunction with imaging module **143** (also called a camera module), optical sensor **164** may capture still images or video. In some embodiments, an optical sensor is located on the back of device **100**, opposite touch screen display **112** on the front of the device, so that the touch screen display may be used as a viewfinder for still and/or video image acquisition. In some embodiments, another optical sensor is located on the front of the device so that the user's image may be obtained for videoconferencing while the user views the other video conference participants on the touch screen display.

Device **100** may also include one or more proximity sensors **166**. FIG. **1**A shows proximity sensor **166** coupled to peripherals interface **118**. Alternately, proximity sensor **166** may be coupled to input controller **160** in I/O subsystem **106**. In some embodiments, the proximity sensor turns off and disables touch screen **112** when the multifunction device is placed near the user's ear (e.g., when the user is making a phone call).

Device **100** includes one or more orientation sensors **168**. In some embodiments, the one or more orientation sensors include one or more accelerometers (e.g., one or more linear accelerometers and/or one or more rotational accelerometers). In some embodiments, the one or more orientation sensors include one or more gyroscopes. In some embodiments, the one or more orientation sensors include one or more magnetometers. In some embodiments, the one or more orientation sensors include one or more of global positioning system (GPS), Global Navigation Satellite System (GLONASS), and/or other global navigation system receivers.

The GPS, GLONASS, and/or other global navigation system receivers may be used for obtaining information concerning the location and orientation (e.g., portrait or landscape) of device **100**. In some embodiments, the one or more orientation sensors include any combination of orientation/rotation sensors. FIG. **1**A shows the one or more orientation sensors **168** coupled to peripherals interface **118**. Alternately, the one or more orientation sensors **168** may be coupled to an input controller **160** in I/O subsystem **106**. In some embodiments, information is displayed on the touch screen display in a portrait view or a landscape view based on an analysis of data received from the one or more orientation sensors.

In some embodiments, the software components stored in memory **102** include operating system **126**, communication module (or set of instructions) **128**, contact/motion module (or set of instructions) **130**, graphics module (or set of instructions) **132**, text input module (or set of instructions) **134**, Global Positioning System (GPS) module (or set of instructions) **135**, arbiter module **157** and applications (or sets of instructions) **136**. Furthermore, in some embodiments memory **102** stores device/global internal state **157**, as shown in FIGS. **1**A and **3**. Device/global internal state **157** includes one or more of: active application state, indicating which applications, if any, are currently active; display state, indicating what applications, views or other information occupy various regions of touch screen display **112**; sensor state, including information obtained from the device's various sensors and input control devices **116**; and location information concerning the device's location and/or attitude.

Operating system **126** (e.g., Darwin, RTXC, LINUX, UNIX, OS X, WINDOWS, or an embedded operating system such as VxWorks) includes various software components and/or drivers for controlling and managing general system tasks (e.g., memory management, storage device control, power management, etc.) and facilitates communication between various hardware and software components.

Communication module **128** facilitates communication with other devices over one or more external ports **124** and also includes various software components for handling data received by RF circuitry **108** and/or external port **124**. External port **124** (e.g., Universal Serial Bus (USB), FIREWIRE, etc.) is adapted for coupling directly to other devices or indirectly over a network (e.g., the Internet, wireless LAN, etc.). In some embodiments, the external port is a multi-pin (e.g., 30-pin) connector.

Contact/motion module **130** may detect contact with touch screen **112** (in conjunction with display controller **156**) and other touch sensitive devices (e.g., a touchpad or physical click wheel). Contact/motion module **130** includes various software components for performing various operations related to detection of contact, such as determining if contact has occurred (e.g., detecting a finger-down event), determining if there is movement of the contact and tracking the movement across the touch-sensitive surface (e.g., detecting one or more finger-dragging events), and determining if the contact has ceased (e.g., detecting a finger-up event or a break in contact). Contact/motion module **130** receives contact data from the touch-sensitive surface. Determining movement of the point of contact, which is represented by a series of contact data, may include determining speed (magnitude), velocity (magnitude and direction), and/or an acceleration (a change in magnitude and/or direction) of the point of contact. These operations may be applied to single contacts (e.g., one finger contacts) or to multiple simultaneous contacts (e.g., "multitouch"/multiple finger contacts). In some embodiments, contact/motion module **130** and display controller **156** detect contact on a touchpad.

Contact/motion module **130** may detect a gesture input by a user. Different gestures on the touch-sensitive surface have different contact patterns. Thus, a gesture may be detected by detecting a particular contact pattern. For example, detecting a finger tap gesture includes detecting a finger-down event followed by detecting a finger-up (lift off) event at the same position (or substantially the same position) as the finger-down event (e.g., at the position of an icon). As another example, detecting a finger swipe gesture on the touch-sensitive surface includes detecting a finger-down event followed by detecting one or more finger-dragging events, and subsequently followed by detecting a finger-up (lift off) event.

Graphics module **132** includes various known software components for rendering and displaying graphics on touch screen **112** or other display, including components for changing the intensity of graphics that are displayed. As used herein, the term "graphics" includes any object that can be displayed to a user, including without limitation text, web pages, icons (such as user-interface objects including soft keys), digital images, videos, animations and the like.

In some embodiments, graphics module **132** stores data representing graphics to be used. Each graphic may be assigned a corresponding code. Graphics module **132** receives, from applications etc., one or more codes specifying graphics to be displayed along with, if necessary, coordinate data and other graphic property data, and then generates screen image data to output to display controller **156**.

Text input module **134**, which may be a component of graphics module **132**, provides soft keyboards for entering text in various applications (e.g., contacts **137**, e-mail **140**, IM **141**, browser **147**, and any other application that needs text input).

GPS module **135** determines the location of the device and provides this information for use in various applications (e.g., to telephone **138** for use in location-based dialing, to camera **143** as picture/video metadata, and to applications that provide location-based services such as weather widgets, local yellow page widgets, and map/navigation widgets).

Applications **136** may include the following modules (or sets of instructions), or a subset or superset thereof:

- contacts module **137** (sometimes called an address book or contact list);
- telephone module **138**;
- video conferencing module **139**;
- e-mail client module **140**;
- instant messaging (IM) module **141**;
- workout support module **142**;
- camera module **143** for still and/or video images;
- image management module **144**;
- browser module **147**;
- calendar module **148**;
- widget modules **149**, which may include one or more of: weather widget **149-1**, stocks widget **149-2**, calculator widget **149-3**, alarm clock widget **149-4**, dictionary widget **149-5**, and other widgets obtained by the user, as well as user-created widgets **149-6**;
- widget creator module **150** for making user-created widgets **149-6**;
- search module **151**;
- video and music player module **152**, which may be made up of a video player
- module and a music player module;
- notes module **153**;
- map module **154**; and/or
- online video module **155**.

Examples of other applications **136** that may be stored in memory **102** include other word processing applications, other image editing applications, drawing applications, presentation applications, JAVA-enabled applications, encryption, digital rights management, voice recognition, and voice replication.

In conjunction with touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, and text input module **134**, contacts module **137** may be used to manage an address book or contact list (e.g., stored in application internal state **192** of contacts module **137** in memory **102** or memory **370**), including: adding name(s) to the address book; deleting name(s) from the address book; associating telephone number(s), e-mail address(es), physical address(es) or other information with a name; associating an image with a name; categorizing and sorting names; providing telephone numbers or e-mail addresses to initiate and/or facilitate communications by telephone **138**, video conference **139**, e-mail **140**, or IM **141**; and so forth.

In conjunction with RF circuitry **108**, audio circuitry **110**, speaker **111**, microphone **113**, touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, and text input module **134**, telephone module **138** may be used to enter a sequence of characters corresponding to a telephone number, access one or more telephone numbers in address book **137**, modify a telephone number that has been entered, dial a respective telephone number, conduct a conversation and disconnect or hang up when the conversation is completed. As noted above, the wireless communication may use any of a variety of communications standards, protocols and technologies.

In conjunction with RF circuitry **108**, audio circuitry **110**, speaker **111**, microphone **113**, touch screen **112**, display controller **156**, optical sensor **164**, optical sensor controller **158**, contact module **130**, graphics module **132**, text input module **134**, contact list **137**, and telephone module **138**, videoconferencing module **139** includes executable instructions to initiate, conduct, and terminate a video conference between a user and one or more other participants in accordance with user instructions.

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, and text input module **134**, e-mail client module **140** includes executable instructions to create, send, receive, and manage e-mail in response to user instructions. In conjunction with image management module **144**, e-mail client module **140** makes it very easy to create and send e-mails with still or video images taken with camera module **143**.

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, and text input module **134**, the instant messaging module **141** includes executable instructions to enter a sequence of characters corresponding to an instant message, to modify previously entered characters, to transmit a respective instant message (for example, using a Short Message Service (SMS) or Multimedia Message Service (MMS) protocol for telephony-based instant messages or using XMPP, SIMPLE, or IMPS for Internet-based instant messages), to receive instant messages and to view received instant messages. In some embodiments, transmitted and/or received instant messages may include graphics, photos, audio files, video files and/or other attachments as are supported in a MMS and/or an Enhanced Messaging Service (EMS). As used herein, "instant messaging" refers to both telephony-based messages (e.g., messages sent using SMS or MMS) and Internet-based messages (e.g., messages sent using XMPP, SIMPLE, or IMPS).

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, text input module **134**, GPS module **135**, map module **154**, and music player module **146**, workout support module **142** includes executable instructions to create workouts (e.g., with time, distance, and/or calorie burning goals); communicate with workout sensors (sports devices); receive workout sensor data; calibrate sensors used to monitor a workout; select and play music for a workout; and display, store and transmit workout data.

In conjunction with touch screen **112**, display controller **156**, optical sensor(s) **164**, optical sensor controller **158**, contact module **130**, graphics module **132**, and image management module **144**, camera module **143** includes executable instructions to capture still images or video (including a video stream) and store them into memory **102**, modify characteristics of a still image or video, or delete a still image or video from memory **102**. Some embodiments of camera module **143** include instructions for control of a zoom lens actuator, as described herein.

In conjunction with touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, text input module **134**, and camera module **143**, image management module **144** includes executable instructions to arrange, modify (e.g., edit), or otherwise manipulate, label, delete, present (e.g., in a digital slide show or album), and store still and/or video images.

In conjunction with RF circuitry **108**, touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, and text input module **134**, browser module **147** includes executable instructions to browse the Internet in accordance with user instructions, including searching, linking to, receiving, and displaying web pages or portions thereof, as well as attachments and other files linked to web pages.

In conjunction with RF circuitry **108**, touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, text input module **134**, e-mail client module **140**, and browser module **147**, calendar module **148** includes executable instructions to create, display, modify, and store calendars and data associated with calendars (e.g., calendar entries, to do lists, etc.) in accordance with user instructions.

In conjunction with RF circuitry **108**, touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, text input module **134**, and browser module **147**, widget modules **149** are mini-applications that may be downloaded and used by a user (e.g., weather widget **149-1**, stocks widget **149-2**, calculator widget **1493**, alarm clock widget **149-4**, and dictionary widget **149-5**) or created by the user (e.g., user-created widget **149-6**). In some embodiments, a widget includes an HTML (Hypertext Markup Language) file, a CSS (Cascading Style Sheets) file, and a JavaScript file. In some embodiments, a widget includes an XML (Extensible Markup Language) file and a JavaScript file (e.g., Yahoo! Widgets).

In conjunction with RF circuitry **108**, touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, text input module **134**, and browser module **147**, the widget creator module **150** may be used by a user to create widgets (e.g., turning a user-specified portion of a web page into a widget).

In conjunction with touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, and text input module **134**, search module **151** includes executable instructions to search for text, music, sound, image, video, and/or other files in memory **102** that match one or more search criteria (e.g., one or more user-specified search terms) in accordance with user instructions.

In conjunction with touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, audio circuitry **110**, speaker **111**, RF circuitry **108**, and browser module **147**, video and music player module **152** includes executable instructions that allow the user to download and play back recorded music and other sound files stored in one or more file formats, such as MP3 or AAC files, and executable instructions to display, present or otherwise play back videos (e.g., on touch screen **112** or on an external, connected display via external port **124**). In some embodiments, device **100** may include the functionality of an MP3 player.

In conjunction with touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, and text input module **134**, notes module **153** includes executable instructions to create and manage notes, to do lists, and the like in accordance with user instructions.

In conjunction with RF circuitry **108**, touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, text input module **134**, GPS module **135**, and browser module **147**, map module **154** may be used to receive, display, modify, and store maps and data associated with maps (e.g., driving directions; data on stores and other points of interest at or near a particular location; and other location-based data) in accordance with user instructions.

In conjunction with touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, audio circuitry **110**, speaker **111**, RF circuitry **108**, text input module **134**, e-mail client module **140**, and browser module **147**, online video module **155** includes instructions that allow the user to access, browse, receive (e.g., by streaming and/or download), play back (e.g., on the touch screen or on an external, connected display via external port **124**), send an e-mail with a link to a particular online video, and otherwise manage online videos in one or more file formats, such as H.264. In some embodiments, instant messaging module **141**, rather than e-mail client module **140**, is used to send a link to a particular online video.

Each of the above identified modules and applications correspond to a set of executable instructions for performing one or more functions described above and the methods described in this application (e.g., the computer-implemented methods and other information processing methods described herein). These modules (i.e., sets of instructions) need not be implemented as separate software programs, procedures or modules, and thus various subsets of these modules may be combined or otherwise re-arranged in various embodiments. In some embodiments, memory **102** may store a subset of the modules and data structures identified above. Furthermore, memory **102** may store additional modules and data structures not described above.

In some embodiments, device **100** is a device where operation of a predefined set of functions on the device is performed exclusively through a touch screen and/or a touchpad. By using a touch screen and/or a touchpad as the primary input control device for operation of device **100**, the number of physical input control devices (such as push buttons, dials, and the like) on device **100** may be reduced.

The predefined set of functions that may be performed exclusively through a touch screen and/or a touchpad include navigation between user interfaces. In some embodiments, the touchpad, when touched by the user, navigates device **100** to a main, home, or root menu from any user interface that may be displayed on device **100**. In such embodiments, the touchpad may be referred to as a "menu button." In some other embodiments, the menu button may be a physical push button or other physical input control device instead of a touchpad.

FIG. **2** illustrates a portable multifunction device **100** having a touch screen **112** in accordance with some embodiments. The touch screen may display one or more graphics within user interface (UI) **200**. In this embodiment, as well as others described below, a user may select one or more of the graphics by making a gesture on the graphics, for example, with one or more fingers **202** (not drawn to scale in the figure) or one or more styluses **203** (not drawn to scale in the figure).

Device **100** may also include one or more physical buttons, such as "home" or menu button **204**. As described previously, menu button **204** may be used to navigate to any application **136** in a set of applications that may be executed on device **100**. Alternatively, in some embodiments, the menu button is implemented as a soft key in a GUI displayed on touch screen **112**.

In one embodiment, device **100** includes touch screen **112**, menu button **204**, push button **206** for powering the device on/off and locking the device, volume adjustment button(s) **208**, Subscriber Identity Module (SIM) card slot **210**, head set jack **212**, and docking/charging external port **124**. Push button **206** may be used to turn the power on/off on the device by depressing the button and holding the button in the depressed state for a predefined time interval; to lock the device by depressing the button and releasing the button before the predefined time interval has elapsed; and/or to unlock the device or initiate an unlock process. In an alternative embodiment, device **100** also may accept verbal input for activation or deactivation of some functions through microphone **113**.

It should be noted that, although many of the following examples will be given with reference to optical sensor/camera **164** on the front of a device such as a tablet computer or telephone, a rear-facing camera or optical sensor that is pointed opposite from the display may be used instead of optical sensor/camera **164** on a front surface. Other portable electronic devices, such as laptops or tablet computers with cameras, may also be used. It should also be understood that, in some embodiments, the device is not a portable communications device, but is a desktop or laptop computer with a camera. In some embodiments, the device is a gaming computer with cameras (e.g., in a gaming controller). It should also be noted that the terms moving and movable are used interchangeably herein.

Zoom Actuator Mechanism

Some embodiments provide a zoom actuator system. In some embodiments, a moving body slides on a fixed chassis structure. In some embodiments, the fixed chassis structure substantially limits the motion of the moving body to one linear degree of freedom.

Some embodiments minimize the number of components in the tolerance stack between lens groups, and reduce or eliminate clearances that can cause an uncertainty in position of the lens groups, such as may be observed with a change in camera orientation.

Unlike other miniature camera actuator mechanisms, such as for auto-focus (AF) and Optical Image Stabilization (OIS), the movement of the different lens groups tends much greater, when normalized with for example the image sensor size, with the result that it is frequently impractical to use an arrangement of resilient flexures to suspend the moving lens group and guide its motion, and some friction is generated as each lens group is slid up and down some kind of guide structure.

Friction creates issues such as wear and positional accuracy, but some embodiments employ the presence of friction to provide some useful features. In some embodiments, the friction is designed to be great enough to support the weight of the lens group and moving portion of the mechanism. Thus, in some embodiments, once positioned, the actuator consumes less power to maintain position. Some embodiments are designed such that an arrangement of magnets is used to generate the normal contact load between the moving portion and fixed guide structure, such that some clearances can be eliminated improving positional accuracy of the lens group.

In some embodiments, the only contact between the moving portion and the fixed structure of the actuator is through the frictional interface, which makes the actuator much more robust against very high external accelerations, such as those very high external accelerations experienced, for example, when the multifunction device is dropped onto the floor. In some embodiments, one class of actuator mechanisms involves an actuator (for example a motor) mounted on the fixed portion of the actuator, and then a drive train (for example a leadscrew and nut) to convert this motion to a linear motion of the lens group. In some embodiments, the actuator is designed to achieve the driving force through the frictional contact surfaces, such that high accelerations result in slippage of the moving portion on its guide structure, rather than high loads that might otherwise damage components.

In some embodiments, the same fixed guide structures are used for plural moving portions that can move independently. In some embodiments, the presence and use of friction means that positional accuracy is less certain, and hence a position sensing means is incorporated for each moving portion.

Non-limiting embodiments of the present invention will now be presented with the aid of the accompanying illustrations. In some embodiments, the basic operation of the actuator is to use piezo (piezoelectric element) as an inertial exciter. FIG. **3** depicts schematic operation of an inertial actuator, according to some embodiments. An actuator assembly **300** includes a piezo **310** situated between an inertial mass **320** and a moving body **330**. Motion **340** of moving body **330** is generated by slowly contracting **350** and quickly expanding **360** piezo **310**.

FIG. **4** illustrates schematic operation of an inertial actuator, according to some embodiments. An actuator assembly **400** includes a piezo **410** situated between an inertial mass **420** and a moving body **430**. Motion **440** of moving body **430** is generated by slowly expanding **450** and quickly contracting **460** piezo **410**. On one side, piezo **410** is joined to moving body **430**, which may include a lens group of a zoom lens apparatus. On the other side is inertial mass **420**. By dynamically deforming the shape of piezo **410** in response to applied voltages, piezo **410** accelerates inertial mass **420**. The inertial forces for motion **440** are transmitted to the moving body **430**.

FIG. **5** illustrates a long-throw actuator assembled with its housing, according to some embodiments. A zoom actuator system **500** includes a chassis (external housing **570**). In some embodiments, the external housing is composed of a magnetic material, such as a magnetic steel, to which a moving actuator carriage **530** is articulated. Moving actuator carriage **530** is, in some embodiments, formed from a non-magnetic material, such as aluminum. Though not visible in the embodiment shown in FIG. **5**, in some embodiments a second independent moving actuator carriage **580** is also included. Embodiments vary the length of chassis **570** to fit particular needs. Two sides of the chassis form contact surfaces (tracks **590**), which provide substantially rigid contact surfaces for moving actuator carriage **530**.

Chassis **570** provides a structure that can guide the moving actuator carriage **530** along the degree of freedom of interest, which in the case of the zoom actuator **500** is parallel to the optical axis. Moving actuator carriage **530** also contains one or more magnets (not shown in FIG. **5**), to provide an appropriate normal preload force on all the contact surfaces (e.g. internal tracts **590**) between the moving actuator carriage **530** and chassis **570**. In this way there is a friction force between the between the moving actuator carriage **530** and chassis **570**.

The size of the piezo (not visible in FIG. **5**) and inertial mass **520** are chosen such that inertial acceleration forces can overcome the static friction. If driven with a sine wave, which is symmetric, then in the nominal case over time, there will be no net movement. However if the oscillatory waveform is asymmetric, then it can be arranged that in one direction, the inertial forces can overcome the static friction, whilst in the other direction, they are essentially lower and in the ideal case there is no reverse motion. In this way, over multiple cycles, the between the moving actuator carriage **530** and can work its way along chassis **570**

In the configuration shown in FIG. **5**, some embodiments transmit electrical signals to the piezo (not visible in FIG. **5**) on the moving actuator carriage **530** using a ribbon connector or flexible printed circuit (not shown). In some embodiments, a driver integrated circuit (IC) (not shown) for the piezo (not shown) is also mounted on the moving actuator carriage **530**, and digital communication to the driver IC to request a movement is routed via the ribbon connector or flexible printed circuit (not shown). In some embodiments, a convenient communication protocol is I^2C, which uses two terminals. I^2C is a multi-master serial single-ended computer bus used for attaching low-speed peripherals to a motherboard. In some embodiments, I^2C uses two bidirectional open-drain lines, a Serial Data Line (SDA) and a Serial Clock (SCL), pulled up with resistors. Typical voltages used are +5 V or +3.3 V although systems with other voltages are permitted.

The I^2C reference design has a 7-bit or a 10-bit (depending on the device used) address space. Common I^2C bus speeds are the 100 kbit/s standard mode and the 10 kbit/s low-speed mode, but arbitrarily low clock frequencies are also allowed. Recent revisions of I^2C can host more nodes and run at faster speeds (400 kbit/s Fast mode, 1 Mbit/s Fast mode plus or Fm+, and 3.4 Mbit/s High Speed mode). These speeds are more widely used on embedded systems than on PCs. There are also other features, such as 16-bit addressing.

In addition, in some embodiments the driver IC uses two power terminals (typically power and ground). Therefore for this configuration, there are four electrical terminals used by the moving actuator carriage **530**. Some embodiments allow multiple moving bodies (e.g., moving actuator carriage **530** and a second independent moving actuator carriage) to be running on the same tracks **590**, by ensuring the driver ICs on moving actuator carriage **530** and second independent moving actuator carriage have different I^2C addresses, and hence may communicate on the same I^2C bus. Such embodiments allow a lens of a second independent moving actuator carriage to be moved relative to a lens in a lens group mounting feature of moving actuator carriage **530**. A hall sensor or (in alternative embodiments a capacitive position sensing pattern allows the position of each of moving actuator carriage **530** and the second independent moving actuator carriage to be independently measured.

FIG. **6** depicts a long-throw actuator assembled with its housing, according to some embodiments. A zoom actuator system **600** includes a chassis **670**, to which a moving actuator carriage **630** is articulated. A lens group mount **652** for carrying one or more lenses **622** is shown within the moving actuator carriage **630** of zoom actuator assembly **600**. Chassis **670** provides a structure that guides the moving actuator carriage **630** along the degree of freedom of interest.

Moving actuator carriage **630** contains one or more magnets **682**, to provide an appropriate normal preload force (magnetic forces **616**) in opposition to contact forces **614** between the moving actuator carriage **630** and chassis **670**. In this way there is a friction force between the between the moving actuator carriage **630** and chassis **670**. The piezo is not visible, but an inertial mass **674** mounted to the piezo is shown. A driver circuit **624** is also shown.

In some embodiments, the carriage **630** in the chassis structure **670**, and the direction of the contact forces **614** on the carriage **630** are shown. In some embodiments, relative to the image sensor (not shown), the carriage **630** in principle has six degrees of freedom; three orthogonal linear directions, and rotations about three orthogonal axes. The degree of freedom used for is movement in or out of the page as viewed in FIG. **6**, which is parallel with the optical axis for a typical zoom lens **622** configuration.

FIG. **7** illustrates a cutaway view of a long-throw actuator assembled with its housing, according to some embodiments. A zoom actuator system **700** includes a fixed chassis structure **770**. In some embodiments, the fixed chassis structure **770** includes a magnetic friction track at a contact surface **792**. In some embodiments, a moveable carriage body **780** carries one or more lenses (not shown in FIG. **7**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**). One or more magnets **790** is mounted to the moveable carriage body **780**. In some embodiments, the moveable carriage body is movably mounted at contact surface **792** to the chassis **770** to allow movement along an optical axis through the one or more lenses (not shown in FIG. **7**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**).

In some embodiments, an inertial actuator **710** is mounted to the moveable carriage body **780** in an alignment such that the axis of motion of the actuator **710** is parallel to the optical axis through the one or more lenses (not shown in FIG. **7**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**). In some embodiments, the moveable carriage body **780** is held in place with respect to the at least one allowed degree of freedom by one or more friction forces at contact surface **792** resulting from the magnetic attraction force created by the one or more magnets **790**.

In some embodiments, the moveable carriage body includes one or more datum surfaces, such as contact surface **792**. In some embodiments, the datum surfaces serve as points of frictional contact between the moveable carriage and magnetic friction track. In some embodiments, the moveable carriage does not touch the fixed chassis structure except at the points of contact, such as contact surface **792**, between the datum surfaces and the magnetic friction track.

In some embodiments, the fixed chassis structure **770** includes an external housing of non-magnetic material. In some embodiments, the magnetic friction track includes a strip of magnetic material.

FIG. **8** depicts an actuator carriage without its housing, according to some embodiments. A zoom actuator system includes a fixed chassis structure (not shown in FIG. **8**). In some embodiments, the fixed chassis structure (not shown in FIG. **8**) includes a magnetic friction track at a contact surface (not shown in FIG. **8**) for meeting a contact surface **882** of a moveable carriage body **800**. In some embodiments, the moveable carriage body **800** carries one or more lenses (not shown in FIG. **8**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**). One or more magnets **890** is mounted to the moveable carriage body **800**. In some embodiments, the moveable carriage body **800** is movably mounted at contact surfaces **882** to the chassis (not shown in FIG. **8**) to allow movement along an optical axis through the one or more lenses (not shown in FIG. **8**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**).

In some embodiments, an inertial actuator (not shown in FIG. **8**) is mounted to the moveable carriage body **800** in an alignment such that the axis of motion of the actuator (not shown in FIG. **8**) and an attached inertial mass **820** are parallel to the optical axis through the one or more lenses (not shown in FIG. **8**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**). In some embodiments, the moveable carriage body **800** is held in place with respect to the at least one allowed degree of freedom by one or more friction forces at contact surfaces **882** resulting from the magnetic attraction force created by the one or more magnets **890**.

In some embodiments, the moveable carriage body includes one or more datum surfaces, such as contact surfaces **882**. In some embodiments, the datum surfaces serve as points of frictional contact between the moveable carriage and magnetic friction track. In some embodiments, the moveable carriage does not touch the fixed chassis structure except at the points of contact, such as contact surface **882**, between the datum surfaces and the magnetic friction track.

FIG. **9** illustrates carriage construction and connection features, according to some embodiments. A zoom actuator system **900** includes a chassis **970**, to which a moving actuator carriage **930** is moveably articulated. Chassis **970** provides a structure that guides the moving actuator carriage **930** along the degree of freedom of interest.

Moving actuator carriage **930** contains one or more magnets **982**, to provide an appropriate normal preload force (not shown in FIG. **9**, but an example magnetic force is visible in FIG. **6** as magnetic forces **616**) in opposition to contact forces (not shown in FIG. **9**, but an example contact force is visible in FIG. **6** as contact forces **614**) between the moving actuator carriage **930** and chassis **970**. In this way there is a friction force between the between the moving actuator carriage **930** and chassis **970**. The piezo is not visible, but an inertial mass **974** mounted to the piezo is shown. A driver circuit **924** is also shown.

In some embodiments, relative to the image sensor (not shown), the carriage **930** in principle has six degrees of freedom; three orthogonal linear directions, and rotations about three orthogonal axes. The degree of freedom used for is movement up and down the page as viewed in FIG. **9**, which is parallel with the optical axis for a typical zoom lens configuration. In some embodiments, the moveable carriage body **930** receives power and control signals to the inertial actuator through a flexible printed circuit **952** configured to coil behind and unwind beneath the moveable carriage body **930** during movement.

FIG. **10** depicts a carriage connector, according to some embodiments. In some embodiments, the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit configured to coil behind and unwind beneath the moveable carriage body during movement. In FIG. **10**, an example flexible printed circuit is shown in a coiled state **1072** and a straightened state **1074**.

FIG. **11** depicts a carriage and connector, according to some embodiments. In some embodiments, the driver circuit **1102** on the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit **1104** configured to coil behind and unwind beneath the moveable carriage body during movement.

FIG. **12** depicts a carriage and connector, according to some embodiments. In some embodiments, the driver circuit **1202** on the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit **1204** configured to coil behind and unwind beneath the moveable carriage body during movement.

FIG. **13** illustrates a long-throw actuator assembled with its housing, according to some embodiments. A zoom actuator system **1300** includes a chassis **1370**, to which a moving actuator carriage **1330** is articulated. A lens group mount **1352** for carrying one or more lenses **1322** is shown within the moving actuator carriage **1330** of zoom actuator assembly **1300**. Chassis **1370** provides a structure that guides the moving actuator carriage **1330** along the degree of freedom of interest.

Moving actuator carriage **1330** contains one or more magnets **1382**, to provide an appropriate normal preload force (magnetic forces **1316**) in opposition to contact forces **1314** between the moving actuator carriage **1330** and chassis **1370**. In this way there is a friction force between the between the moving actuator carriage **1330** and chassis **1370**. The piezo is not visible, but an inertial mass **1374** mounted to the piezo is shown. A driver circuit **1324** is also shown. A position measurement track **1304** is shown, which may allow for capacitive or magnetic position measurements by a position sensor **1306**, such as a Hall sensor or a capacitive sensor.

In some embodiments, the carriage **1330** in the chassis structure **1370**, and the direction of the contact forces **1314** on the carriage **1330** are shown. In some embodiments, relative to the image sensor (not shown), the carriage **1330** in principle has six degrees of freedom; three orthogonal linear directions, and rotations about three orthogonal axes. The degree of freedom used for is movement in or out of the page as viewed in FIG. **13**, which is parallel with the optical axis for a typical zoom lens **1322** configuration. In some embodiments, the driver circuit **1324** on the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit **1302** configured to coil behind and unwind beneath the moveable carriage body during movement.

FIG. **14** depicts a carriage and connector, according to some embodiments. A zoom actuator system **1400** includes a chassis (not shown in FIG. **14**, but chassis **670** of FIG. **6** is one example), to which a moving actuator carriage **1430** is articulated. A lens group mount (not shown in FIG. **14**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**) for carrying one or more lenses attaches to moving actuator carriage **1430** of zoom actuator assembly **1400**. Chassis (not shown in FIG. **14**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**) provides a structure that guides the moving actuator carriage **1430** along the degree of freedom of interest.

Moving actuator carriage **1430** contains one or more magnets **1482**, to provide an appropriate normal preload force in opposition to contact forces between the moving actuator carriage **1430** and chassis. In this way there is a friction force between the between the moving actuator carriage **1430** and chassis. The piezo is not visible, but an inertial mass **1422** mounted to the piezo is shown. A driver circuit **1424** is also shown. A position measurement track **1404** is shown, which may allow for capacitive or magnetic position measurements by a position sensor **1406**, such as a Hall sensor or a capacitive sensor.

In some embodiments, the driver circuit **1424** on the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit **1402** configured to coil behind and unwind beneath the moveable carriage body during movement.

FIG. **15** illustrates a cutaway view of a long-throw actuator assembled with its housing, according to some embodiments. A zoom actuator system **1500** includes a chassis (not shown in FIG. **15**, but chassis **670** of FIG. **6** is one example), to which a moving actuator carriage **1530** is articulated. A lens group mount (not shown in FIG. **15**, but an example lens mount group **652** for carrying one or more lenses **622** is visible in FIG. **6**) for carrying one or more lenses attaches to moving actuator carriage **1530** of zoom actuator assembly

1500. Chassis (not shown in FIG. 15, but an example lens mount group 652 for carrying one or more lenses 622 is visible in FIG. 6) provides a structure that guides the moving actuator carriage 1530 along the degree of freedom of interest.

Moving actuator carriage 1530 contains one or more magnets 1582, to provide an appropriate normal preload force in opposition to contact forces between the moving actuator carriage 1530 and chassis. In this way there is a friction force between the between the moving actuator carriage 1530 and chassis. The piezo 1550 moves an inertial mass 1522 mounted to the piezo, to create a motive force (as shown in FIG. 15, up and down the page) to move moving carriage 1530 by overcoming friction forces between the chassis and moving carriage body 1530. A driver circuit 1524 is also shown. A position measurement track 1504 is shown, which may allow for capacitive or magnetic position measurements by a position sensor 1506, such as a Hall sensor or a capacitive sensor.

In some embodiments, the driver circuit 1524 on the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit 1502 configured to coil behind and unwind beneath the moveable carriage body during movement.

In some embodiments, there are several advantages to this basic approach. The inertial loads of the lens group in lens group mount are not taken by the piezo 1550, which increases robustness. In fact during an impact, the piezo 1550 only needs to take the loads of the inertial mass 1522, and its own self weight. The actuator (piezo element 1550) and carriage 1530 are only connected mechanically to the fixed chassis (not shown) via the contact surfaces (e.g., contact surface 792 of FIG. 7), such that there is not extra mechanical or electrical tethering. This absence of extra mechanical or electrical tethering aids robustness. Placing the driver IC 1524 on the carriage 1530 and providing the appropriate electrical connections via contacts FPC 1502 allows additional carriages, in some embodiments, to be mounted on the same chassis structure, minimizing size.

In some embodiments, position sensor 1506 is used required to control the position of the one or more carriages. In some embodiments, this is achieved by using a capacitance sensor, comprising a conductive plate mounted to the carriage 1530 to form a capacitive coupling to a patterned conductive trace on the chassis structure. This trace may ultimately be connected to ground or some other terminal to provide the complete circuit around the capacitor. In some embodiments the shape of this pattern that the effective size of the parallel plate capacitor formed by the overlap between the conductive plate 1504 on the carriage and the patterned trace on the chassis oscillates as the carriage 1530 moves up and down. In such embodiments, the position sensor 1506 operates by measuring the capacitance of this parallel plate capacitor. Some embodiments include one or more resistors to be in the capacitor circuit loop, which may for example be mounted on the carriage FPC 1502 next to the driver 1524. From a home position, at maybe one end of travel of the actuator, as the carriage 1530 moves along the chassis, the number of capacitance oscillations indicates the gross position of the carriage 1530 in the chassis, whereas the actual capacitance value provides a finer measure of position. In other embodiments, position sensor 1506 is a Hall sensor.

In some embodiments, the moving body contacts the chassis at multiple surfaces so as to constrain the motion, and at least a proportion of each of these contact surfaces provides frictional force to control motion. In some embodiments, the inertial actuator is driven with an asymmetric oscillatory electrical signal so that in one half of the cycle the inertial acceleration is higher than in the other, and during at least a portion of the oscillatory motion, the inertial forces exceed the static friction of the contact points and cause sliding in the allowed linear degree of freedom.

In some embodiments, multiple such oscillatory cycles, in combination, yield a net motion of the moving body in one direction relative to the chassis, and the reverse motion can be achieved by appropriately altering the asymmetric electrical signal.

FIG. 16 is a flowchart of a method for operating a zoom actuator, according to one embodiment. A magnetic attraction force between a moveable lens carriage body and a fixed chassis structure is generated using one or more magnets mounted to the moveable lens carriage body (block 1610). A varying voltage is applied to an inertial actuator attached to the moveable lens carriage body (block 1620).

FIG. 17 is a flowchart of a method for operating a zoom actuator, according to one embodiment. A magnetic attraction force between a moveable lens carriage body and a fixed chassis structure is generated using one or more magnets mounted to the moveable lens carriage body (block 1710). A varying voltage is applied to an inertial actuator attached to the moveable lens carriage body to generate stick-slip motion of the moveable carriage assembly by asymmetrically breaking the friction forces between moveable carriage assembly and the magnetic friction track so as to generate net movement of the carriage along the track (block 1720).

FIG. 18 is a flowchart of a method for operating a zoom actuator, according to one embodiment. A magnetic attraction force between a moveable lens carriage body and a fixed chassis structure is generated using one or more magnets mounted to the moveable lens carriage body (block 1810). A varying voltage is applied to an inertial actuator attached to the moveable lens carriage body (block 1820). A varying second voltage is applied to an electromagnet among the one or more magnets to adjust the friction forces (block 1780).

FIG. 19 is a flowchart of a method for operating a zoom actuator, according to one embodiment. A magnetic attraction force between a moveable lens carriage body and a fixed chassis structure is generated using one or more magnets mounted to the moveable lens carriage body, such that the moveable carriage body is held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from the magnetic attraction force between the one or more magnets and a magnetic friction track of the moveable carriage structure (block 1910). A varying voltage is applied to a piezoelectric inertial actuator attached to the moveable lens carriage body, such that variations in the varying voltage cause an expansion and a contraction of the piezoelectric element, and the contraction is slower than the expansion, resulting in a net force created along a line of motion of the piezoelectric actuator during motion of the moveable lens carriage body that is greater than the one or more friction forces resulting from the magnetic attraction force (block 1920).

Example Computer System

FIG. 20 illustrates computer system 2000 that is configured to execute any or all of the embodiments described above. In different embodiments, computer system 2000 may be any of various types of devices, including, but not limited to, a personal computer system, desktop computer, laptop, notebook, tablet, slate, or netbook computer, mainframe computer system, handheld computer, workstation, network computer, a camera, a set top box, a mobile device, a consumer device, video game console, handheld video game device, application server, storage device, a television, a video recording device, a peripheral device such as a switch, modem, router, or in general any type of computing or electronic device.

Various embodiments of a camera motion system as described herein, may be executed in one or more computer systems **2000**, which may interact with various other devices. Note that any component, action, or functionality described above with respect to FIGS. **1-20** may be implemented on one or more computers configured as computer system **2000** of FIG. **20**, according to various embodiments. In the illustrated embodiment, computer system **2000** includes one or more processors **2010** coupled to a system memory **2020** via an input/output (I/O) interface **2030**. Computer system **2000** further includes a network interface **2040** coupled to I/O interface **2030**, and one or more input/output devices **2050**, such as cursor control device **2060**, keyboard **2070**, and display(s) **2080**. In some cases, it is contemplated that embodiments may be implemented using a single instance of computer system **2000**, while in other embodiments multiple such systems, or multiple nodes making up computer system **2000**, may be configured to host different portions or instances of embodiments. For example, in one embodiment some elements may be implemented via one or more nodes of computer system **2000** that are distinct from those nodes implementing other elements.

In various embodiments, computer system **2000** may be a uniprocessor system including one processor **2010**, or a multiprocessor system including several processors **2010** (e.g., two, four, eight, or another suitable number). Processors **2010** may be any suitable processor capable of executing instructions. For example, in various embodiments processors **2010** may be general-purpose or embedded processors implementing any of a variety of instruction set architectures (ISAs), such as the x86, PowerPC, SPARC, or MIPS ISAs, or any other suitable ISA. In multiprocessor systems, each of processors **2010** may commonly, but not necessarily, implement the same ISA.

System memory **2020** may be configured to store camera control program instructions **2022** and/or camera control data accessible by processor **2010**. In various embodiments, system memory **2020** may be implemented using any suitable memory technology, such as static random access memory (SRAM), synchronous dynamic RAM (SDRAM), nonvolatile/Flash-type memory, or any other type of memory. In the illustrated embodiment, program instructions **2022** may be configured to implement a lens control application **2024** incorporating any of the functionality described above. Additionally, existing camera control data **2032** of memory **2020** may include any of the information or data structures described above. In some embodiments, program instructions and/or data may be received, sent or stored upon different types of computer-accessible media or on similar media separate from system memory **2020** or computer system **2000**. While computer system **2000** is described as implementing the functionality of functional blocks of previous Figures, any of the functionality described herein may be implemented via such a computer system.

In one embodiment, I/O interface **2030** may be configured to coordinate I/O traffic between processor **2010**, system memory **2020**, and any peripheral devices in the device, including network interface **2040** or other peripheral interfaces, such as input/output devices **2050**. In some embodiments, I/O interface **2030** may perform any necessary protocol, timing or other data transformations to convert data signals from one component (e.g., system memory **2020**) into a format suitable for use by another component (e.g., processor **2010**). In some embodiments, I/O interface **2030** may include support for devices attached through various types of peripheral buses, such as a variant of the Peripheral Component Interconnect (PCI) bus standard or the Universal Serial Bus (USB) standard, for example. In some embodiments, the function of I/O interface **2030** may be split into two or more separate components, such as a north bridge and a south bridge, for example. Also, in some embodiments some or all of the functionality of I/O interface **2030**, such as an interface to system memory **2020**, may be incorporated directly into processor **2010**.

Network interface **2040** may be configured to allow data to be exchanged between computer system **2000** and other devices attached to a network **2085** (e.g., carrier or agent devices) or between nodes of computer system **2000**. Network **2085** may in various embodiments include one or more networks including but not limited to Local Area Networks (LANs) (e.g., an Ethernet or corporate network), Wide Area Networks (WANs) (e.g., the Internet), wireless data networks, some other electronic data network, or some combination thereof. In various embodiments, network interface **2040** may support communication via wired or wireless general data networks, such as any suitable type of Ethernet network, for example; via telecommunications/telephony networks such as analog voice networks or digital fiber communications networks; via storage area networks such as Fibre Channel SANs, or via any other suitable type of network and/or protocol.

Input/output devices **2050** may, in some embodiments, include one or more display terminals, keyboards, keypads, touchpads, scanning devices, voice or optical recognition devices, or any other devices suitable for entering or accessing data by one or more computer systems **2000**. Multiple input/output devices **2050** may be present in computer system **2000** or may be distributed on various nodes of computer system **2000**. In some embodiments, similar input/output devices may be separate from computer system **2000** and may interact with one or more nodes of computer system **2000** through a wired or wireless connection, such as over network interface **2040**.

As shown in FIG. **20**, memory **2020** may include program instructions **2022**, which may be processor-executable to implement any element or action described above. In one embodiment, the program instructions may implement the methods described above. In other embodiments, different elements and data may be included. Note that data may include any data or information described above.

Those skilled in the art will appreciate that computer system **2000** is merely illustrative and is not intended to limit the scope of embodiments. In particular, the computer system and devices may include any combination of hardware or software that can perform the indicated functions, including computers, network devices, Internet appliances, PDAs, wireless phones, pagers, etc. Computer system **2000** may also be connected to other devices that are not illustrated, or instead may operate as a stand-alone system. In addition, the functionality provided by the illustrated components may in some embodiments be combined in fewer components or distributed in additional components. Similarly, in some embodiments, the functionality of some of the illustrated components may not be provided and/or other additional functionality may be available.

Those skilled in the art will also appreciate that, while various items are illustrated as being stored in memory or on storage while being used, these items or portions of them may be transferred between memory and other storage devices for purposes of memory management and data integrity. Alternatively, in other embodiments some or all of the software components may execute in memory on another device and communicate with the illustrated computer system via inter-computer communication. Some or all of the system components or data structures may also be stored (e.g., as instructions or structured data) on a computer-accessible medium or a portable article to be read by an appropriate drive, various examples of which are described above. In some embodiments, instructions stored on a computer-accessible medium separate from computer system **2000** may be transmitted to computer system **2000** via transmission media or signals such as electrical, electromagnetic, or digital signals, conveyed via a communication medium such as a network and/or a wireless link. Various embodiments may further include receiving, sending or storing instructions and/or data implemented in accordance with the foregoing description upon a computer-accessible medium. Generally speaking, a computer-accessible medium may include a non-transitory, computer-readable storage medium or memory medium such as magnetic or optical media, e.g., disk or DVD/CD-ROM, volatile or non-volatile media such as RAM (e.g. SDRAM, DDR, RDRAM, SRAM, etc.), ROM, etc. In some embodiments, a computer-accessible medium may include transmission media or signals such as electrical, electromagnetic, or digital signals, conveyed via a communication medium such as network and/or a wireless link.

The methods described herein may be implemented in software, hardware, or a combination thereof, in different embodiments. In addition, the order of the blocks of the methods may be changed, and various elements may be added, reordered, combined, omitted, modified, etc. Various modifications and changes may be made as would be obvious to a person skilled in the art having the benefit of this disclosure. The various embodiments described herein are meant to be illustrative and not limiting. Many variations, modifications, additions, and improvements are possible. Accordingly, plural instances may be provided for components described herein as a single instance. Boundaries between various components, operations and data stores are somewhat arbitrary, and particular operations are illustrated in the context of specific illustrative configurations. Other allocations of functionality are envisioned and may fall within the scope of claims that follow. Finally, structures and functionality presented as discrete components in the exemplary configurations may be implemented as a combined structure or component. These and other variations, modifications, additions, and improvements may fall within the scope of embodiments as defined in the claims that follow.

What is claimed is:

1. A system, comprising:

a fixed chassis structure, wherein

the fixed chassis structure comprises a magnetic friction track; and

a moveable carriage body, wherein

the moveable carriage body carries one or more lenses,

one or more magnets is mounted to the moveable carriage body,

the moveable carriage body is movably mounted to the fixed chassis structure to allow movement along an optical axis through the one or more lenses,

an inertial actuator is mounted to the moveable carriage body in an alignment such that an axis of motion of the inertial actuator is parallel to the optical axis through the one or more lenses, and

the moveable carriage body is held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from a magnetic attraction force of the one or more magnets.

2. The system of claim **1**, wherein

the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit configured to coil behind and unwind beneath the moveable carriage body during movement.

3. The system of claim **1**, wherein:

the one or more magnets comprise one or more electromagnets.

4. The system of claim **1**, wherein:

the moveable carriage body comprises one or more datum surfaces, wherein

the datum surfaces serve as points of frictional contact between the moveable carriage body and magnetic friction track.

5. The system of claim **1**, wherein

the moveable carriage body does not touch the fixed chassis structure except at the points of contact between the datum surfaces and the magnetic friction track.

6. The system of claim **1**, wherein

the fixed chassis structure comprises an external housing of non-magnetic material.

7. The system of claim **1**, wherein

the magnetic friction track comprises a strip of magnetic material mounted inside an enclosure formed by the fixed chassis structure.

8. A camera module, comprising:

one or more lenses that define an optical axis;

an image sensor; and

an actuator assembly, comprising:

a fixed chassis structure comprising a magnetic friction track;

a moveable carriage body that carries the one or more lenses;

one or more magnets mounted to the moveable carriage body; and

an inertial actuator mounted to the moveable carriage body in an alignment such that an axis of motion of the inertial actuator is parallel to the optical axis;

wherein:

the moveable carriage body is movably mounted to the fixed chassis structure to allow movement along the optical axis; and

the moveable carriage body is held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from a magnetic attraction force of the one or more magnets.

9. The camera module of claim **8**, wherein:

the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit configured to coil behind and unwind beneath the moveable carriage body during movement.

10. The camera module of claim **8**, wherein:

the one or more magnets comprise one or more electromagnets.

11. The camera module of claim **8**, wherein:

the moveable carriage body comprises one or more datum surfaces; and

the datum surfaces serve as points of frictional contact between the moveable carriage body and magnetic friction track.

12. The camera module of claim 8, wherein:
the moveable carriage does not touch the fixed chassis structure except at the points of contact between the datum surfaces and the magnetic friction track.
13. The camera module of claim 8, wherein:
the fixed chassis structure comprises an external housing of non-magnetic material.
14. The camera module of claim 8, wherein:
the magnetic friction track comprises a strip of magnetic material mounted inside an enclosure formed by the fixed chassis structure.
15. A mobile multifunction device, comprising:
a camera module, including:
one or more lenses that define an optical axis;
an image sensor; and
an actuator assembly, comprising:
a fixed chassis structure comprising a magnetic friction track;
a moveable carriage body that carries the one or more lenses;
one or more magnets mounted to the moveable carriage body; and
an inertial actuator mounted to the moveable carriage body in an alignment such that an axis of motion of the inertial actuator is parallel to the optical axis;
wherein:
the moveable carriage body is movably mounted to the fixed chassis structure to allow movement along the optical axis; and
the moveable carriage body is held in place with respect to at least one allowed degree of freedom by one or more friction forces resulting from a magnetic attraction force of the one or more magnets;
a display; and
one or more processors to:
cause the camera module to capture an image; and
cause the display to present the image.
16. The mobile multifunction device of claim 15, wherein:
the moveable carriage body receives power and control signals to the inertial actuator through a flexible printed circuit configured to coil behind and unwind beneath the moveable carriage body during movement.
17. The mobile multifunction device of claim 15, wherein:
the one or more magnets comprise one or more electromagnets.
18. The mobile multifunction device of claim 15, wherein:
the moveable carriage body comprises one or more datum surfaces; and
the datum surfaces serve as points of frictional contact between the moveable carriage body and magnetic friction track.
19. The mobile multifunction device of claim 15, wherein:
the moveable carriage does not touch the fixed chassis structure except at the points of contact between the datum surfaces and the magnetic friction track.
20. The mobile multifunction device of claim 15, wherein:
the fixed chassis structure comprises an external housing of non-magnetic material.

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